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Human responses to environmental change on the southern coastal plain of the Caspian Sea during the Mesolithic and Neolithic periods

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Abstract

This paper presents results of a multidisciplinary research initiative examining human responses to environmental change at the intersection of the southern coastal plain of the Caspian Sea and the foothills of the Alborz Mountains during the terminal Pleistocene and early Holocene. Our palaeo-environmental analysis of two sedimentary cores obtained from a lagoon in close proximity to four caves, occupied by human groups during the transition from hunting and gathering to food-producing ways of life in this region, confirms Charles McBurney's 1968 hypothesis that when Caspian Sea levels were high, Mesolithic hunters were reliant on seal and deer, but as water levels receded and a wide coastal plain emerged, hunters consumed a different range of herbivorous mammalian species.

Palynological evidence obtained from these two cores also demonstrates that the cool and dry climatic conditions often associated with the Younger Dryas stadial do not appear to have been extreme in this region. Thus, increasingly sedentary hunting and gathering groups could have drawn

on plant and animal resources from multiple ecological niches without suffering significant resource stress or reduced population levels that may have been encountered in neighbouring regions. Our analyses of botanical, faunal and archaeological remains from a recently-discovered open-air Mesolithic and aceramic Neolithic site also shows an early process of Neolithization in the southern Caspian basin, which was a very gradual, low-cost adaptation to new ways of life, with neither the abandonment of hunting and gathering, nor a climatic trigger event for the emergence of a low-level, food-producing society.

Key words (3-7 words)

Palynology; Archaeology; Caspian Sea levels; Vegetation dynamics; Human response; faunal and botanical evidence; Neolithization; Pleistocene-Holocene transition; Palaeogeography; Middle East

1 Introduction

Many studies have been conducted to reveal the history of the Caspian Sea (CS) level changes and to reconstruct terrestrial palaeoenvironments using coastal and marine archives (Leroy et al., in press). However, the impact of environmental changes on early human communities in the region remains poorly understood.

Researchers have long been interested in examining the prehistoric ways of life of foraging groups and early food-producing societies between the CS and the Alborz Mountains and Kopet Dagh in northern Iran and southern Turkmenistan (Pumpelly, 1905; Arne, 1935; Okladnikov, 1949, 1956; Coon, 1951, 1952, 1957; Movius, 1953; Masson, 1957; McBurney, 1964,1968) (Fig. 1A and B). The region is rich in archaeological remains. Lower Palaeolithic tools have been found in the lower valley of the Sefidrud River, a major waterway draining into the southern Caspian basin (Fig. 1A; Biglari et al., 2004), while Mousterian tools point to Neanderthal occupation of the Keyaram Cave in the central Alborz (Berillon et al., 2007a) and the eastern shore of the Caspian north of Krasnovodsk Bay (Fig. 1A; Okladnikov, 1949; Dolukhanov et al., 2010). The open-air site of Garm Roud 2 on the northern slopes of the Alborz has yielded a lithic assemblage of bladelets, burins and scrapers, as well as bones of red deer and aurochs with evidence of butchery by humans dated to approximately 35,000 yr BP (Berillon et al., 2007b). The coastal plain is also rich in younger archaeological sites, including four caves adjacent to the southern coastal plain of the CS have also yielded abundant evidence of human occupations during the Mesolithic and/or early Neolithic periods (Coon, 1951,1952, 1957; McBurney, 1964, 1968; Vahdati Nasab et al., 2011), and animal bones from these sites provide an opportunity to reconstruct changes in diet of the region's prehistoric inhabitants. In a comparison of frequencies of faunal remains recovered from three of these caves, McBurney (1968) proposed that the proximity of the Caspian shoreline would have had a substantial influence on the range and number of animals available for human subsistence.

The Alborz Mountains in northern Iran offer a diverse range of environments with north-facing slopes that capture precipitation from air masses coming from the CS (Fig. 1A). This humid region represents a teaming pocket of life in an otherwise arid Middle East. Today, the coastal plain between the modern cities of Behshahr and Gorgan is the eastern-most region with sufficient precipitation for diversified agriculture, before lands become progressively drier the closer to their proximity to the Karakum Desert in western Turkmenistan (Molavi-Arabshahi et al., 2016) (Fig. 1A). The northern Alborz Mountains end in a relatively narrow coastal plain whose width varies in accordance with CS levels (Mamedov, 1997; Naderi Beni et al., 2013a,b). Sea level changes along with orography facilitated great biodiversity throughout the region, and provided glacial refuges for plants, which in turn contributed to both animal and human subsistence during late prehistoric periods (Leroy and Arpe, 2007; Arpe et al., 2011).

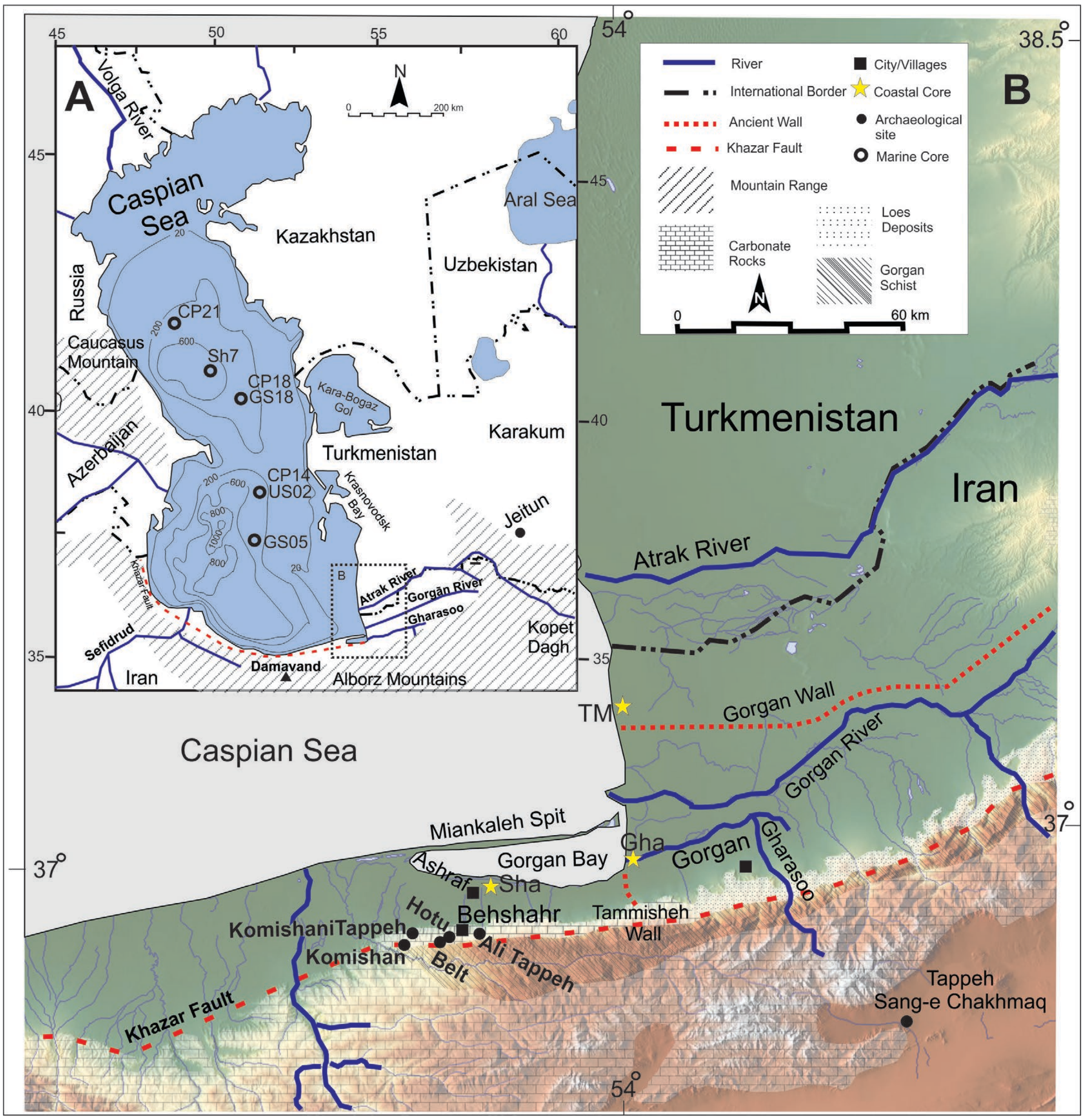


Fig. 1: Location maps.
1A: Map of the Caspian Sea, with main marine cores.
1B: Detailed map of the SE corner of the southern Caspian basin showing major geological formations and locations of the sedimentary coring sites and Mesolithic and Neolithic archaeological sites mentioned in the text.

The aim of this study is to reconstruct past changes in terrestrial and coastal environments, with an emphasis on human interactions with the landscapes on which they lived during the terminal Pleistocene and early Holocene. Consequently, we obtained two sedimentary cores, each approximately 17 m in long from the sites of Shahkileh and Gharasoo, adjacent to a shallow lagoon, the Gorgan Bay, on the southern coastal plain of CS in close proximity to five archaeological sites (Fig. 1B). The results are integrated herewith in context of an radiocarbon chronology associated with bioarchaeological data from a recently-discovered open-air Mesolithic and aceramic Neolithic site at Komishani Tappeh (Fig. 1B).

2 Regional setting

The CS is currently 28 m below modern ocean levels, with the Alborz Mountains rising up to 5670 m asl at the Damavand volcano (Fig. 1A). Our study area is located between the uplifting mountains and the subsiding southern Caspian basin (Brunet et al., 2003) (Fig. 1A). Since the Last Glacial Maximum pronounced changes in CS levels may have reached 150 m in amplitude (Leroy et al., in press).

High water levels up to 50 m asl occurred in the early stages of the early Khvalynian, that is poorly dated but is most likely post Last Glacial Maximum (Makshaev et al., 2015; Arslanov et al., 2016). This is followed by highstands reaching 35 and 22 m asl around 16-14 cal. ka BP. Then in the Late Khvalynian (14-12 cal. ka BP), water levels reached only 0 and 12 m bsl (Makshaev et al., 2015; Arslanov et al., 2016). A sharp drop (to perhaps as much as 113 m bsl) occurred with the Mangyshlak lowstand at the beginning of the Holocene lasting from one millennium in the deep-sea basin (Leroy et al., 2014) to three millennia in the shallow north basin (Bezrodnykh and Sorokin, 2016). This is followed by a further rapid increase to a highstand of unknown height, and ultimately to late Holocene intermediate levels beginning approximately 4000 years ago (Leroy et al., 2013a, 2019, in press; Naderi et al., 2013a,b). Even minor changes in water levels have a strong influence on the south-eastern coast of the CS, especially where it is close to the mountains in the south or where water is shallow in the south-east (Naderi Beni et al., 2014) (Fig. 1A).

The two sedimentary cores examined in this study were obtained from the southern and eastern shores of Gorgan Bay in an area of undifferentiated Quaternary: either flood plain or old terraces (Fig. 1B) (Amini, 2012). This ~400 km^2 tectonically controlled, shallow bay (maximum 4 m depth) spans 70 km on its east-west axis, and is for the most part closed to the greater expanse of the CS (Amini et al., 2012). The Miankaleh Spit, a series of sandy dunes that reach a maximum of 4 m above modern CS levels, separates the brackish waters of the bay (0-11 psu) from the CS (12-13 psu) (Fig. 1B). North of the Miankaleh Spit, the water depth is quite shallow (less than 50 m) and remains so, as it merges with the wide shelf of the eastern Caspian coast (Fig. 1A). In the east, the Gorgan Bay is connected to the CS by a narrow inlet (Leroy et al., 2018; Kouhanestani et al., 2019). The freshening of the bay is due to water inflow from rivers originating in the Alborz Mountains. Several perennial and ephemeral streams flow into the bay, of which the Gharasoo (or Qara-Su, Qareh-Sou) is the largest (Fig. 1B). The river has a drainage area of

1638 km^2 and its length is 89 km (Kurdi et al., 2013). Currently the river mouth of the Gharasoo is made up of fine sandy sediment (Gharibreza et al., 2018). It has been hypothesized that the river course would extend into the bay during periods of regression in CS levels (Ownegh, 2010).

Surface sediments of the bay change from fine sand to mud that is finer in the west with some patches of coarse sand and sandy mud in the northern parts (Lahijani et al., 2010; Amini et al., 2012). The average of total organic carbon in the bay sediment is about 27% that decreases coastward to around 18% and peaks up to 29% in the central parts of the bay (Amini et al., 2012). Average carbonate content of the sediment is around 36% that increases to around 40% in the Miankaleh Spit and is less than 34% in the southern coast of the Gorgan Bay (Amini et al., 2012).

Apart from Gorgan green schist and dolomite outcrops that are exposed south of the bay and at the foothills of the Alborz, limestone is the predominant rock type of the catchment basin (Fig. 1B), which provides detritic carbonates to the Gorgan Bay (Lahijani et al., 2010, in press). These karstic limestones (Parent et al., 2012) are host to several caves that were occupied by humans during the terminal Pleistocene and early Holocene (Coon, 1951, 1952; McBurney, 1968). Belt, Hotu, Ali Tappeh and Komishan Caves overlook the coastal plain of the CS from heights ranging between 45 to 58 meters asl (Fig. 1B). Detailed analyses of the karstic processes resulting in formation of these chambers has yet to be undertaken. However, Coon (1951, 1952) and McBurney (1968) both suggested that the caverns they excavated were originally shaped by marine erosion. The dissolution of carbonate rock could have been facilitated by wave erosion during prolonged CS highstands and the mixing of rain and lake waters saturated with different amounts of carbon dioxide (Karkanas and Goldberg, 2017). Carbonate bedrocks are also found to the east of the Gorgan Bay in the Kopet Dagh. Carbonates are carried by strong winds and westward-flowing rivers to the sea and contribute to form a marine sediment rich in detritic carbonates (Lahijani et al., in press).

The south-eastern coastal plain is currently intensively cultivated with rare remnants of alluvial forests: *Alnus glutinosa* associated with *Populus caspica, Pterocarya fraxinifolia, Ulmus minor, Cornus australis, Alnus subcordata, Diospyros lotus, Buxus hyrcana* and *Ilex spinigera* (Akhani et al., 2010). North of the Gharasoo River, a dry region contains salt-rich soils and halophytic vegetation. Large *Phragmites australis* communities grow inside and around the bay, with dense communities of submerged aquatic plants such as *Ruppia maritima.* The coastal zone is composed of *Salicornia*, *Aster tripolium* and *Suaeda crassifolia*. Furthermore, species of *Juncus*, *Typha*, *Tamarix* and *Alhagi maurorum* grow over saline soils around the Gorgan Bay. A series of east-west vegetation belts cover the northern slopes of the Alborz Mountains. From bottom to top, these belts start with alluvial forests in the west, grading in the east progressively into a steppe with *Artemisia* and *Astragalus* at sea level. This belt is succeeded by a lowland forest (rich in Tertiary relict species) up to ~500 m, then by the oak, hornbeam and beech mountain species up to ~2000 m. A slightly drier *Quercus macranthera* forest succeeds this up to ~2500 m, with *Juniper* woodland and the alpine meadows at higher elevations (Akhani et al., 2010; Encyclopaedia Iranica, no date).

North of the Gharasoo River, semi-arid climate conditions prevail: dry and hot in the summer and cool in winter, with mean annual precipitation of 300 mm and mean annual temperature of 17.5 ºC (Honardoust et al., 2011). The climate to the west is wetter and cooler, with up to 1850 mm of annual precipitation and mean annual temperatures between 15.5 and 16 ºC (Molavi-Arabshahi et al., 2016).

3 Previous palynological and archaeological investigations

3.1 Regional palynology and the Shahkileh and Gharasoo sequences

Four previous palynological datasets span parts of the last 14,400 years (Fig. 1A). Three of them are offshore: the combined sequence of cores GS05-CP14-US02 in the south basin (Leroy et al., 2007 and 2013a), the combined sequence of cores GS18-CP18 in the middle basin (Leroy et al., 2007 and 2014; Tudryn et al., 2016; Leroy et al., 2019), and core Sh7 in the North of the middle basin (Leroy et al., 2019). The TM sequence is from a coastal lagoon (palaeo-Gomishan) in the SE corner of the CS, only 35 km North of the coring site of Gharasoo (Fig. 1B; Leroy et al., 2013c). Modern pollen spectra at the site of the two cores and the caves were previously published in Leroy et al. (2013a). They show the dominance of *Alnus* and *Carpinus betulus,* and a good representation of *Fagus* and *Quercus*. Moreover the modern sites near Gharasoo have high Amaranthaceae values.

The two cores (Shahkileh and Gharasoo), lithological descriptions and sedimentological analyses were part of the doctoral thesis of Amini (2012). Initial chronological information has been briefly published (Amini et al., 2012): comprising two radiocarbon dates on each core.

3.2 Archaeological sites

Archaeological, faunal and botanical remains from Belt, Hotu, Ali Tappeh and Komishan Caves and the recently-discovered open-air site at Komishani Tappeh (Fig. 1B) provide a window into human behaviour in response to changes in environmental conditions during the terminal Pleistocene and early Holocene (Coon, 1951, 1952; McBurney, 1968; Vahdati Nasab et al., 2011; Fazeli Nashli and Gregg 2018; Fazeli Nashli et al., in preparation). Stone tools broadly similar to those of the Mesolithic Trialetian culture of the Caucasus, Eastern Anatolia, Transcaspia and the Iranian Plateau (Kozlowski, 1996) were recovered from basal and subsequent hunter-gatherer occupations of these five sites. This chipped-stone industry includes a variety of lithic elements such as asymmetric triangles, geometrics, backed flakes and backed bladelets, scrapers, perforators and lamelles Dufour. Jayez and Vahdati Nasab (2016) have recently isolated these lithic assemblages as a geographic variant of the Trialetian culture distinctive to northern Iran and western Turkmenistan and renamed them as belonging to the “Caspian Mesolithic”. With the exception of Ali Tappeh Cave, the Mesolithic occupations of the sites listed above are all overlain by aceramic or pottery-bearing Neolithic horizons. Summaries of these horizons can be found in Tables 1 and 2 along with radiocarbon ages (BP) and calibrated dates BC (2 sigma) of charcoal or bone obtained from within them.

3.2.1 Belt and Hotu Caves

Coon excavated Belt and Hotu Caves (sites within 100 m of each other) to depths of six and twelve m respectively over a course of nine weeks in 1949 and 1951 (Coon, 1951, 1952). Radiocarbon assays of twenty charcoal samples from eleven Mesolithic and nine Neolithic levels at these sites were undertaken by Libby (1951) and Ralph (1955) (Table 1).

Site	Lab number	Material	Trench	Cultural / climate phase	Fauna / environment identified	^{14}C BP	Calibrated BC	Reference
Belt Cave	C-492	Charcoal	21-28	Lower Mesolithic 1949	*Seal, gazelle, horse, deer, canid*	8244 ± 740	9401-5719	Libby 1951; McBurney 1968
Belt Cave	C-574	Charcoal	15-16	Upper Mesolithic 1949	Gazelle, sheep / goat, auroch, deer	8800 ± 515	9401-6631	Libby 1951; McBurney 1968
Belt Cave	C-524	Charcoal	10	Mesolithic/Neolithic 1949	N/D	10875 ± 630	12530-9120	Libby 1951; McBurney 1968
Belt Cave	C-494	Charcoal	N/D	Pottery Neolithic 1949	*Seal, gazelle, sheep / goat, pig*	8325 ± 740	9461-5788	Libby 1951; McBurney 1968
Belt Cave	P-19	Charcoal	C	Soft ware Neolithic 1951	*Seal, gazelle, sheep / goat, pig*	7225 ± 420	7140-5360	Ralph 1955; McBurney 1968
Belt Cave	P-19a	Charcoal	C	Soft ware Neolithic 1951	*Seal, gazelle, sheep / goat, pig*	7620 ± 510	7789-5556	Ralph 1955; McBurney 1968
Belt Cave	P-19b	Charcoal	C	Soft ware Neolithic 1951	*Seal, gazelle, sheep / goat, pig*	7650 ± 475	7682-5633	Ralph 1955; McBurney 1968
Belt Cave	P-26	Charcoal	C	Aceramic Neolithic 1951	N/D	7910 ± 485	8014-5996	Ralph 1955; McBurney 1968
Belt Cave	P-26a	Charcoal	C	Aceramic Neolithic 1951	N/D	8140 ± 490	8349-6059	Ralph 1955; McBurney 1968
Belt Cave	P-24	Charcoal	C	Gazelle Mesolithic 1951	Gazelle, sheep / goat, auroch, deer	9050 ± 590	10167-6820	Ralph 1955; McBurney 1968
Belt Cave	P-24a	Charcoal	C	Gazelle Mesolithic 1951	Gazelle, sheep / goat, auroch, deer	8610 ± 525	9189-6481	Ralph 1955; McBurney 1968
Belt Cave	P-27	Charcoal	C	Mesolithic Loess 1951	N/D	12640 ± 850	15635-11116	Ralph 1955; McBurney 1968
Belt Cave	P-20	Charcoal	C	Seal Mesolithic 1951	*Seal, gazelle, horse, deer, canid*	11740 ± 825	14571-9875	Ralph 1955; McBurney 1968
Belt Cave	P-20b	Charcoal	C	Seal Mesolithic 1951	*Seal, gazelle, horse, deer, canid*	11900 ± 775	14655-10432	Ralph 1955; McBurney 1968
Hotu Cave	P-35	Charcoal	HA39-41	Soft ware Neolithic 1951	Sheep / goat, auroch, deer, canid	4870 ± 330	4399-2880	Ralph 1955; McBurney 1968
Hotu Cave	P-36	Charcoal	HB	Soft ware Neolithic 1951	Sheep / goat, auroch, deer, canid	6575 ± 440	6396-4582	Ralph 1955; McBurney 1968
Hotu Cave	P-37	Charcoal	HD	Sub-Neolithic 1951	Sheep / goat, auroch, pig, canid	8310 ± 515	8745-6216	Ralph 1955; McBurney 1968
Hotu Cave	P-12	Charcoal	HD	Mesolithic (vole) 1951	Vole	9465 ± 610	10721-7514	Ralph 1955; McBurney 1968
Hotu Cave	P-38	Charcoal	HD	Mesolithic (vole) 1951	Vole	9500 ± 610	10724-7540	Ralph 1955; McBurney 1968
Hotu Cave	P-39	Charcoal	HD	Mesolithic (seal) 1951	Seal, gazelle, sheep / goat,	12215 ± 865	15303-10688	Ralph 1955; McBurney 1968
Ali Tappeh Cave	GX-0691	Charcoal	C21	Younger Dryas	Gazelle, sheep / goat, horse, canid	10520 ± 410	11262 - 9251	McBurney 1968
Ali Tappeh Cave	GX-0699	Charcoal	A1	Younger Dryas	Gazelle, sheep / goat, horse, canid	10780 ± 320	11407 - 9801	McBurney 1968
Ali Tappeh Cave	GX-0693	Charcoal	Sg14a	Allerød	*Seal, sheep / goat, auroch. canid*	10315 ± 410	11093 - 9118	McBurney 1968
Ali Tappeh Cave	GX-0694	Charcoal	B8	Allerød	*Seal, sheep / goat, auroch. canid*	11640 ± 410	12888 - 10770	McBurney 1968
Ali Tappeh Cave	GX-0695	Charcoal	Sg12	Allerød	*Seal, sheep / goat, auroch. canid*	11330 ± 410	12390 - 10432	McBurney 1968
Ali Tappeh Cave	GX-0696	Charcoal	A13	Allerød	*Seal, sheep / goat, auroch. canid*	11460 ± 370	12363 - 10686	McBurney 1968
Ali Tappeh Cave	GX-0700	Charcoal	A7	Allerød	*Seal, sheep / goat, auroch. canid*	11240 ± 360	12022 - 10564	McBurney 1968
Ali Tappeh Cave	GX-0689	Charcoal	63/16	Allerød	*Seal, sheep / goat, auroch. canid*	11380 ± 410	12481 - 10469	McBurney 1968
Ali Tappeh Cave	GX-0690	Charcoal	A26a	Older Dryas	Gazelle, sheep / goat	12410 ± 480	14145 - 11458	McBurney 1968
Ali Tappeh Cave	GX-0692	Charcoal	C17	Bølling	Gazelle, sheep / goat. canids	12430 ± 600	14547 - 11245	McBurney 1968
Ali Tappeh Cave	GX-0697	Charcoal	A10	Oldest Dryas	Gazelle, sheep / goat, auroch	12510 ± 380	13991 - 11757	McBurney 1968

***Table 1**: Radiocarbon assays from Coon's 1949 and 1951 excavations at Belt and Hotu Caves and McBurney's 1963 and 1964 excavations at Ali Tappeh Cave for 2 sigma (95.4%). In bold: dates used for figure 6. In italics: horizons with evidence of human predation on seals or of highstand.*

Radiocarbon assays of charcoal from basal Mesolithic levels at Belt and Hotu Caves place the earliest Mesolithic hunter-gatherer occupations of the sites between 14655-10432 cal. BC and 15303-10688 cal. BC, respectively (Table 1). Coon's description of five enigmatic unfired clay cones (1951: 75) acknowledges a Mesolithic "interest in clay" at Belt Cave, which is also evidenced at Hotu Cave in a "lump of fired clay showing textile or cordage marks" (Coon, 1952: 247) and a fired clay "goddess figurine recovered from its "Pleistocene gravels"" (Dupree, 1952: 253). An assay of charcoal from a hearth associated with two human skeletons recovered from Gravel IV at a depth of 9.5 m in Hotu Cave yielded a radiocarbon age of 9500 ± 610 BP (Ralph, 1955), which when calibrated falls between 10724 and 7540 cal. BC (Table 1). More recent AMS analyses of collagen surviving in a tooth from skeletal remains of another individual recovered from the same Gravel IV layer has yielded a radiocarbon age of 8855-8637 cal. BC (Table 2) (McAuley, 2013; Beta Analytic, 2013).

Site	Lab number	Material	Trench	Cultural / climate phase	Fauna / environment identified	^{14}C BP	Calibrated BC	Reference
Hotu Cave	Beta-344447	Human	HD	Mesolithic (vole) 1951	Vole	9480±40	8855-8637	Beta Analytic 2013
Hotu Cave	Poz-81124	Human	HD	Mesolithic (vole) 1951	Vole	7250 ± 40	6218-6034	Lazaridis et al. 2016
Ali Tappeh Cave	BM-2726	Charcoal	N/D	Basal Mesolithic	*Caspian transgression*	11240±210	11512-10775	Hedges et al. 1994
Ali Tappeh Cave	BM-2727	Charcoal	N/D	Basal Mesolithic	*Caspian transgression*	11300±190	11532-10806	Hedges et al. 1994
Ali Tappeh Cave	OxA-3194	Charcoal	AT64-A17a	Basal Mesolithic	*Kuma / Bekdash transition 0 bsl*	10800±120	11051-10506	Hedges et al. 1994
Ali Tappeh Cave	OxA-3190	Charcoal	AT64-C11	N/D	Bekdash regression min -55 bsl	10520±100	10731-10149	Hedges et al. 1994
Ali Tappeh Cave	OxA-3192	Charcoal	AT64-A4	End of Mesolithic	*Sartas raised beach -11 to -17 bsl*	10180±110	10291-9441	Hedges et al. 1994
Ali Tappeh Cave	OxA-3191	Marine shell	AT64-Sg9	N/D	Bekdash regression min -55 bsl	11680±110		Hedges et al. 1994
Ali Tappeh Cave	OxA-3193	Marine shell	AT64-CI5	N/D	End of Kuma phase	12640±110		Hedges et al. 1994
Komishan Cave	OxA-22611	charcoal	N/D	Most recent Mesolithic	Gazelle, saiga, pig, canid, birds, fish	10 800±45	10811-10711	Vahdati Nasab et al. 2011
Komishan Cave	OxA-22572	charcoal	N/D	Earliest Mesolithic	Gazelle, saiga, pig, canid, birds, fish	12000±60	12096-11777	Vahdati Nasab et al. 2011
Komishani Tappeh	MAMS-35605	Bone	1. 20	Aceramic Neolithic	Sheep / goat, bird, barley, tuber	9071 ± 33	8309-8242	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35615	charcoal	4. 14	Mesolithic	Sheep / goat, bird, barley, legume	9276 ± 26	8620-8483	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35614	charcoal	4. 13	Aceramic Neolithic	Sheep / goat, bird, barley, legume	9310 ± 26	8634-8529	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35609	charcoal	2. 20. 1	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9260 ± 31	8606-8347	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35610	charcoal	2. 21	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9298 ± 26	8626-8460	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35611	charcoal	2. 23. 4	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9319 ± 26	8639-8533	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35612	charcoal	2. 25. 1	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9297 ± 26	8626-8466	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35613	charcoal	2. 25. 4	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9261 ± 28	8605-8429	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35616	charcoal	4.15	Mesolithic	Sheep / goat, pig, bird, oat, legume	9335 ± 30	8657-8539	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35608	charcoal	2.16. 4	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9697 ± 27	9256-9242	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35617	charcoal	4. 16	No cultural materials	No faunal / botanical macro remains	13470 ± 50	14472-14062	Fazeli Nashli et al. in prep

***Table 2**: AMS radiocarbon ages of materials from Hotu, Ali Tappeh and Komishan caves from the 1990s and 2010s and Komishani Tappeh for 2 sigma (95.4%). In bold: dates used for figure 6. In italics: evidence of human predation on seals or of highstand. N/D: no data.*

An assay of charcoal from a level at Belt Cave identified by Coon as a transitional Mesolithic - Neolithic horizon raises the possibility of the emergence of food production at this site between 12530 and 9120 cal. BC. However, in many instances the hurried methods used in excavation prevent us from clearly differentiating between hunting and gathering and food-producing occupations at these rock shelters (Gregg and Thornton, 2012). The lack of rigour in the recording and curation of finds also restricts our ability to determine whether innovations in subsistence practices at Belt and Hotu Caves, such as the emergence of ‘soft ware’ pottery vessels (Dyson, 1991; Gregg and Thornton, 2012), originated at these sites or were adopted from cultures in adjacent regions. Beyond brief mentions in Coon’s (1951 and 1952) preliminary reports of the discovery of sickle blades, stone mortars, pestles, querns and a small number of unidentified seeds in aceramic and pottery-bearing Neolithic levels at Belt Cave and pottery-bearing Neolithic levels at Hotu Cave, these artefacts and botanical specimens remain unpublished. We have been unable to locate these either in the collections of the University of Pennsylvania Museum or those of the National Museum of Iran. The earliest Neolithic level identified by Coon at Belt Cave is an aceramic horizon falling between 8349 and 6059 cal. BC; whereas the earliest Neolithic level identified by Coon at Hotu Cave is a pottery-bearing horizon falling between 6396 and 4582 cal. BC (Table 1).

3.2.2 Ali Tappeh Cave

Following discovery of Ali Tappeh Cave in 1962, McBurney undertook a preliminary sounding in 1963 and excavated three pits in 1964, all to depths of approximately 6.1 m. These excavations revealed 3.35 m of undisturbed

Mesolithic levels overlain by 2.75 m of Iron Age and later period deposits, many of which appeared to have been pitted and infilled during various later periods in antiquity (McBurney, 1968: 388). Unlike Belt and Hotu Caves, neither aceramic nor pottery-bearing Neolithic levels overlay the Mesolithic occupations at Ali Tappeh. McBurney (1968: 388) attributes the high yield of Mesolithic chipped-stone and bone tools and faunal remains at Ali Tappeh Cave to “greater time and care in specimen recovery” than at Belt and Hotu Caves, and to the repetitive sieving of sediments through a series of progressively smaller meshed screens, rather than the single ½” mesh utilized in Coon’s excavations. Fine bone needles, shell tools and small stone ornaments were recovered through this sieving process (Payne, 1968; Manca et al., 2018), but flotation of sediments was not undertaken in order to isolate and identify botanical macroremains.

Radiocarbon assays of eleven charcoal or wood samples from ten Mesolithic levels undertaken at Geochron Inc. in Boston in 1965 (Table 1; McBurney, 1968), suggested that the Mesolithic deposits at Ali Tappeh Cave could date to a period spanning from 12400 to 10750 uncalibrated BP. Subsequent AMS radiocarbon analyses of charcoal from the basal and most recent Mesolithic levels at Ali Tappeh Cave, and our calibration of radiocarbon ages of these horizons indicate that hunter-gatherer groups visited and potentially occupied the rockshelter between 11500 and 9400 cal. BC (Table 2: BM-2726 and OxA-3192; Hedges et al., 1994).

3.2.3 Komishan Cave

Excavations conducted by Vahdati Nasab and colleagues in 2009 revealed highly-disturbed and potentially-looted stratigraphic levels containing mixtures of Iron Age, Bronze Age and Chalcolithic pottery and Neolithic flint tools overlying an undisturbed Mesolithic horizon (Vahdati Nasab et al., 2011; Jayez and Vahdati Nasab, 2016). Two charcoal samples recovered from the earliest and latest Mesolithic occupations yielded AMS ^{14}C radiocarbon ages of 12096-11777 cal. BC and 10811-10711 cal. BC (Vahdati Nasab et al., 2011).

3.2.4 Komishani Tappeh

In 2017, road-building activities exposed a multi-component prehistoric site within 150 m of Komishan Cave, necessitating salvage excavations and providing two of us (Fazelli Nashli and Gregg, 2018) with the opportunity to investigate the emergence of food-producing ways of life in northern Iran. Our excavation of two trenches (TR1, TR2; Fig. SI 1) adjacent to the area exposed by road builders revealed stratified Bronze Age and Chalcolithic levels overlying a succession of aceramic Neolithic and Mesolithic deposits bearing a ground stone pestle buried to a depth of approximately seven meters beneath the talus slope at the mouth of Komishan Cave. Our concurrent excavation of another trench (TR4; Fig. SI 2) in a suspected looter’s pit on the coastal plain within 500 m of Komishan Cave also revealed undisturbed, stratified aceramic Neolithic and Mesolithic deposits buried to a depth of approximately 4.5 m.

AMS radiocarbon assays of nine charcoal samples and one bone specimen recovered from seven Mesolithic and two Neolithic horizons revealed successive occupations falling between 9200 and 8200 cal. BC (Table 2). An additional charcoal sample, recovered from a basal level in Trench 4 devoid of any identifiable cultural materials, yielded a much earlier age of 14340-14177 cal. BC. While it may be conceivable for Mesolithic hunter-gatherer encampments in northern Iran to fall within this timeframe, the low percentage of carbon (2.2%) recovered from the sample leads us to doubt the reliability of this assay. Assays of a bone specimen and charcoal recovered from aceramic Neolithic contexts bearing small flint blades and pressure-flaked, single-platform cores in Trenches 1 and 4 fall between 8600 and 8200 cal. BC, making Komishani Tappeh significantly older than any other Neolithic site in the Caspian basin, and one of the earliest Neolithic sites in Iran (Fazeli Nashli et al., in preparation). Charcoal from the upper-most Mesolithic horizon able to be dated in Trench 2 yielded the earliest age of 9256-9242 cal. BC (Table 2, MAMS-35608), which is 600 to 700 years earlier than four other charcoal samples from lower stratigraphic levels. A colluvial layer below Neolithic clay-walled architecture and a clay hearth in Trenches 1 and 2 may suggest a hiatus rather than continuity between the aceramic Neolithic and Mesolithic sequences. However, since no stratigraphic unconformity occurs between the aceramic Neolithic and Mesolithic sequences in Trench 4, we suspect that the colluvium was transported from upland areas during a flash flood or a prolonged period of wet climatic conditions, and may be confined to the talus slope in front of Komishan Cave (Fazeli Nashli et al., in preparation).

3.3 Faunal and botanical assemblages

In Coon's reports on 1949 and 1951 excavations at Belt and Hotu Caves, faunal remains from Neolithic occupations were almost exclusively sheep and goat (Coon, 1951). Gazelle, which had been abundant in Upper Mesolithic levels, were notably absent from the Neolithic levels. Goat and aurochs had also begun to appear towards the top of the Upper Mesolithic horizon; whereas, Lower Mesolithic horizons were dominated by red deer, Caspian seal and water birds. To Coon, the faunal remains of sheep and goats from Mesolithic levels at Belt Cave were morphologically indistinguishable from those of domesticated species found in later Neolithic levels. However, the high ratio of young animals in the faunal assemblage led Coon to suspect "goat herding began in the Mesolithic" (Coon, 1951: 41).

In a comparison of faunal remains from Ali Tappeh Cave with the published data from Belt and Hotu Caves, McBurney (1968) hypothesized that a link existed between the diet of its prehistoric inhabitants and the width of CS coastal plain. Frequencies of animal bones from these three sites support McBurney's contention that when water levels were high and the coastal plain was narrow, Mesolithic hunters were reliant on seal and deer; whereas when water levels receded and a wide coastal plain emerged, hunters consumed different range of species, including auroch, onager, boar, gazelle, sheep and goat. To McBurney, the concentration of Neolithic inhabitants of Belt Cave on sheep and/or goat to the virtual exclusion of gazelle suggested an interesting prelude to domestication associated with the emergence of pottery at the site. With the simultaneous appearance of large quantities of pottery and the first morphological evidence of domesticated sheep and goats, "the entire faunal and industrial spectra change as if it were overnight" (McBurney, 1968: 408-

409). The ratio of sheep and goat remains jumps from 12 to 84%, while gazelle drops from 62 to 8%, and aurochs from 22 to 0%.

Shirazi's (unpublished data) analyses of wood charcoal recovered during McBurney's excavations at Ali Tappeh Cave have revealed a diverse range of plant taxa recovered from the Mesolithic occupation levels of the site. Probably also some semi-desert or salinity-rich habitats (goosefoot family) developed in the vicinity. The anthracological assemblages (Shirazi, unpublished data) indicate the most commonly utilised species were obtained from a riparian habitat, followed by the open steppe-forest vegetation represented with a diversity of light-loving small trees and shrubs. The oak may have originated from a steppe-forest habitat nearby the riparian zone where sufficient water was available, while some semi-desert or salinity-rich habitats (goosefoot family) were developed in the vicinity.

Analyses of faunal remains from Komishan Cave by Mashkour et al. (2011) have also provided us with a window into the species exploited by Mesolithic hunters (gazelle, saiga, boar, canid, bird, fish) potentially between 12000 and 10700 cal. BC. Unfortunately, much of the data in this study come from heavily disturbed and undated contexts attributed to later periods.

New botanical and faunal macro-remains obtained from well-dated Mesolithic and aceramic Neolithic contexts at Komishani Tappeh are presented below.

4 Material and Methods

4.1 Cores: Sedimentary, palynological and dating methods

A 17.39 m long core was taken in 2010 using a Swedish K_750 drilling machine with casing and liners in sections of 50 cm and diameter of 15 cm made of PVC tube. The coring operation was conducted when the sea level was slightly higher than today, i.e. ~27.3 m bsl (Chen et al., 2017). The Shahkileh core is located at 36°45'41.40" N, 53°35'54.10" E, at an elevation of 23 m bsl, in a field, 700 m S-SE of the old Shahkileh (Ashraf Port) and 2.2 km from the Gorgan Bay (Fig. 1B). The same method was utilized to obtain a 16.10 m long core on the eastern coast of the Gorgan Bay at the Gharasoo river mouth. The core is located at 36°49'40.16" N, 54° 2'38.61" E, at an elevation of 27 m bsl, c. 600 m far from the coast, along the current river (Fig.1B).

The cores were split and photographed and visually classified into different units based on their texture, colour and shell content (Amini, 2012). For each unit, representative sub-samples were obtained. A Horiba-LA 950 Laser Scattering Particle Size Distribution Analyser at the laboratory of the Iranian National Institute for Oceanography and Atmospheric Science (INIOAS) was used to measure the sediment grain size. Total organic matter content was calculated by adding Hydrogen Peroxide (Schumacher, 2002) and carbonate content was measured by acid attack and a Bernard calcimeter (Lewis and McConchie, 2012). Sediment was classified based on grain-size results according to Folk (1980) using the Sedplot software (Poppe and Eliason, 2008).

The palynological sample volume was between 2 and 2.5 ml. Initial processing of samples involved the addition of sodium pyrophosphate to deflocculate the sediment. Samples were then treated with cold hydrochloric acid (10%) and cold hydrofluoric acid (32%), then HCl again. The residual fraction was screened through 125 and 10 µm mesh sieves. Final residues were mounted on slides in glycerol and sealed with varnish. *Lycopodium* tablets were added at the beginning of the process for concentration estimation in number of pollen and spores per ml of wet sediment (without non-pollen palynomorphs or NPP). The average pollen sum is 335 for the Shahkileh sequence and 318 for the Gharasoo sequence, considering only terrestrial taxa. The percentages of all taxa are calculated on the terrestrial pollen sum. The coprophilous spores here include: *Apiosordaria, Chaetomium, Podospora, Sordaria* and *Sporormiella*. The taxonomy and the ecological preferences of the CS dinocysts have been detailed in Leroy et al. (2013c). An additional form with a morphology between *Galeacysta etrusca* and *Spiniferites cruciformis* A was found. Detailed diagrams are presented in Fig. SI 3 and 4, while diagrams with selected taxa are kept in the main text. The diagrams were plotted using Psimpoll with a 10x exaggeration curves and black dots for values lower than 0.5% (Bennett, 2007). The P/D ratio is the ratio of the concentration of pollen on that of dinocysts (McCarthy and Mudie, 1998).

Radiocarbon dating of the cores was obtained from the Radiocarbon Laboratory of Poznan and the Chrono Centre of Queen's University of Belfast They were made on six samples of shells and one on plant fragments in the Shahkileh sequence and eight from shells in the Gharasoo sequence. The ^{14}C ages were calibrated using INTCAL13 and MAR13 (Stuiver et al., 2018). Various reservoir effects have been quoted for the CS radiocarbon dates; refer to discussion to see how this has been taken in account here. The Lateglacial interstadial and stadial ages are taken from Rasmussen et al. (2014).

4.2 Archaeobotanical and faunal remains and radiocarbon dating

For archaeobotany, we recovered 362 litres of sediment from aceramic Neolithic and Caspian Mesolithic contexts in Trenches 1, 2 and 4 in Komishani Tappeh (Fig. SI 1 and 2), and used machine flotation to collect both light and heavy fractions samples from these sediments at a field facility nearby the site. Samples were subsequently examined with a stereoscopic microscope at the Laboratory for Archaeobotany at the Department of Cultural Heritage in Baden-Württemberg in order to isolate the identifiable morphological characteristics of different botanical macroremains. This was done by using the reference collection of the laboratory and with reference to illustrations in seed atlases, identification manuals and archaeobotanical reports, such as: van Zeist and Bakker-Heeres (1982, 1984, 1985), van Zeist et al. (1984), Cappers et al. (2006, 2009) and Jacomet (2006).

Bone samples were recovered from Trench 4 (Fig. SI 2) both by hand and through use of machine flotation. Hand-recovered animal bones and light and heavy fractions were subsequently examined at the Zooarchaeological Laboratory at the University of Edinburgh. Mammalian identifications were made using the Edinburgh University osteological reference collections, supported by published guides (Schmidt, 1972; Prummel and Frisch, 1986; Zeder and Lapham, 2010; Zeder and Pilaar, 2010). Bird remains were identified using the comparative collections of the Natural History Museum, Tring, UK. Bones not identified to species have been awarded an animal-size category or labelled indeterminate. Identifications reported are provisional. Some of these may change as further work is undertaken. The material is quantified by the number of identified specimens (NISP).

Radiocarbon dating of archaeological horizons in the caves and the open-air site were compiled from the literature and can be assigned to three groups: i) the dates made in the 1950s and 1960s with very large error bars, ii) the dates obtained in the 1990s and iii) the more recent dates with narrower errors made in the 2010s. Most of the dates were made on charcoal, some on bones and only two on marine shells. The radiocarbon assays from Coon's 1949 and 1951 excavations at Belt and Hotu Caves employed Libby's initial calculation of the half-life of ^{14}C of 5568 ± 30 years. Published radiocarbon ages, provided by Libby (1951) and Ralph (1955), have been recalculated using the more accurate Cambridge half-life for ^{14}C of 5730 ± 40 years (Gregg and Thornton, 2012). These radiocarbon ages and those initially published for Ali Tappeh by McBurney (1968) have been calibrated at 95.4% (2 sigma) probability using the Oxcal program (v4.3) of C. Bronk Ramsey and the INTCAL13 dataset (Reimer et al., 2013). The AMS radiocarbon ages of materials from Hotu, Ali Tappeh and Komishan Caves from the 1990s and 2010s and the recently-discovered Komishani Tappeh have been calibrated at 95.4% probability using the Oxcal program (v4.3) of C. Bronk Ramsey and the INTCAL13 dataset (Reimer et al., 2013) and the Calib program (v7.10) of Reimer (Stuiver et al., 2018).

These dates, after eliminating the two dates on marine shells, suggested to be influenced by natural hydrocarbons, and one date, GX-690, deemed unreliable by its author (see Hedges et al., 1994), were organised according to increasing BP ages.

5 Results

5.1 Core lithology and dates

Fig. 2A Leroy et al.

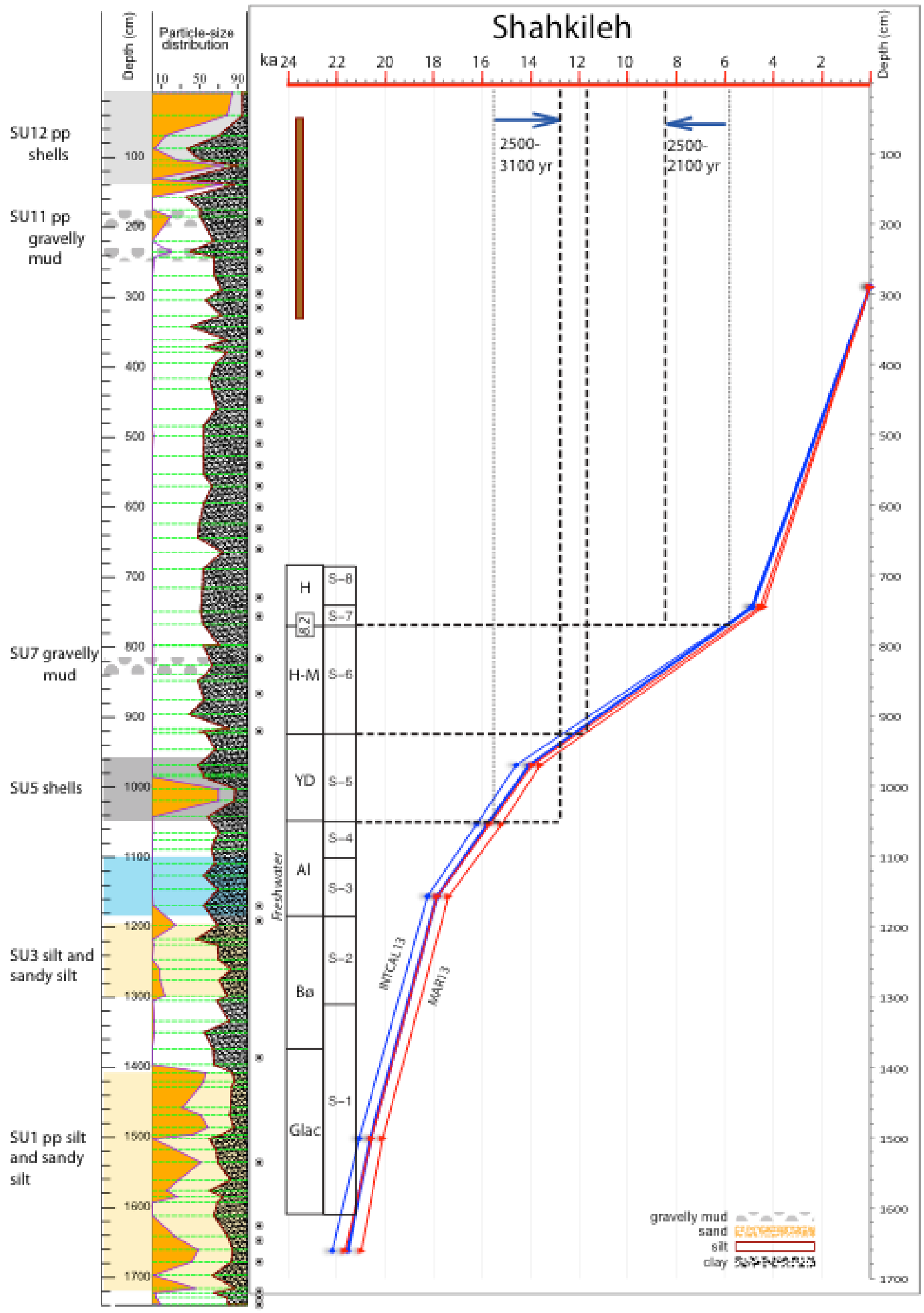


Fig. 2B Leroy et al.

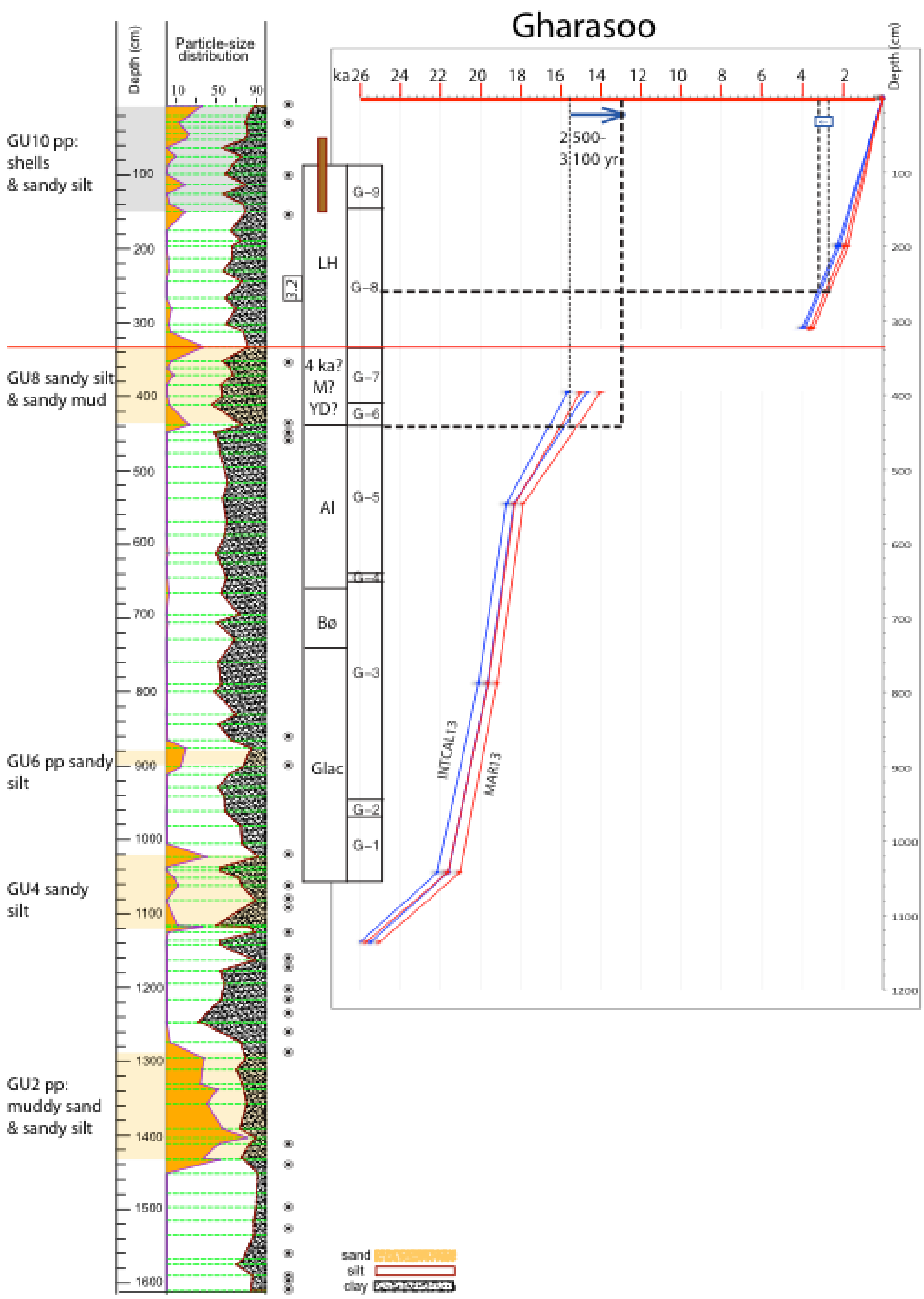


__Fig. 2__: Chronology of Shahkileh (Fig. 2A) and Gharasoo (Fig. 2B) sequences. Details of dates in Table 3. Black dot with circle: barren palynological samples. Light dash lines are ages from radiocarbon dates, whilst heavy dash lines are ages suggested by palynology.

The lithology of the two cores consists of silt and clay with occasional shell-rich horizons, sandy silt or muddy silt. The lithological changes of the Shahkileh sedimentary succession (Fig. 2A and SI 5) are classified in twelve units. Units SU1, SU3, SU5 and SU 11-12 contain sand and/or shells. Units SU 7 and SU11 (840-815, 252-224 and 200-175 cm) are differently made by gravelly mud with some low roundness limestone gravels belonging to the Alborz Upper Jurassic carboniferous formations. The other units consist of clay and silt in more or less equal proportions. Generally, the colour of the sedimentary succession is olive grey to greyish brown. Only units SU10 (upper part), SU11 and SU12 are brown to yellowish brown. The structures are mostly massive, uniform, non-layered or rarely faintly layered. Organic matter (OM) % varies between 1 and 6%, and is especially low in unit SU10 and high in unit SU4. Carbonate content varies between 10 and 40% with a maximal value in units SU4 and SU12.

The Gharasoo sequence (Fig. 2B and SI 5) is divided in ten lithological units. Units GU2 GU4, GU6, GU8 and GU10 contain some sand and/or shells without any gravel content. The rest of the sedimentary succession is silty clay or clayey silt. The colour changes from olive grey to greyish brown. Only the top of unit GU10 turns to brown. The structures are mostly massive, uniform, with alternating non-layered and faintly layered horizons. Total OM varies between 1 and 4%. Carbonate content oscillates between 15 and 40% with a maximum value in unit GU9.

The fifteen dates show no reversal, except the date at 714 cm in Gharasoo, which is considered as an outlier (Table 3, Fig. 2B). The remaining fourteen datings suggest that the base of the core of Shahkileh is clearly older than 22 cal. ka BP and the top reaches the last centuries. The base of the Gharasoo core is close to 25 cal. ka BP and the top likely close to the present. The late Holocene part of the cored sequences will be presented elsewhere.

Core	Lab number	cm depth	Material	uncal ^{14}C BP	uncer-tainty	INTCAL13 AD-BC	MAR13 AD-BC	INTCAL13 BP	MAR13 BP
Sha	POZ-38792	290	shells	*103.42 pMC*	*0.36*	AD 1951-1959*			
Sha	UBA-39063	745-741	broken shells & 1 very small gateropod	4328	21	2922	2510	4872	4460
Sha	UBA-36129	970	plant fragments	12300	51	12291	11820	14241	13770
Sha	UBA-32446	1054	gastropod and bivalves	13311	66	14061	13470	16011	15420
Sha	UBA-32447	1157	9 bivalve valves	14842	65	16101	15649	18051	17599
Sha	UBA-32448	1501	1 Theodoxus	17278	74	18885	18403	20835	20353
Sha	POZ-38790	1661	shells	18040	100	19907	19377	21857	21327
Gha	POZ-38787	199	shells	2225	30	279	AD121	2229	1829
Gha	UBA-36126	310	broken bivalves	3634	25	1996	1584	3946	3534
Gha	UBA-32875	396	broken bivalves	12775	124	13275	12521	15225	14471
Gha	UBA-32449	546	a broken bivalve	15282	74	16605	16141	18555	18091
Gha	UBA-36127	714	broken bivalves	6722	29				
Gha	UBA-32450	787	bivalves	16494	73	17949	17468	19899	19418
Gha	UBA-32451	1042	1 bivalve	18062	78	19935	19409	21885	21359
Gha	POZ-38786	1136	shells	21450	140	23814	23446	25764	25396

***Table 3**: Radiocarbon dating of the Shahkileh (Sha) and Gharasoo (Gha) sequences for 2 sigma (95.4%). Star: post-modern age suggested by T. Goslar, Poznan laboratory (pers. comm., 2019).*

5.2 Palynology of the Shahkileh sequence

The palynological sequence (58 good samples interspersed by 12 barren samples, Fig. 3 and Fig. SI 3) extends from 1610 to 680 cm depth, with six additional barren samples at the bottom and 16 additional ones at the top (Fig. 2).

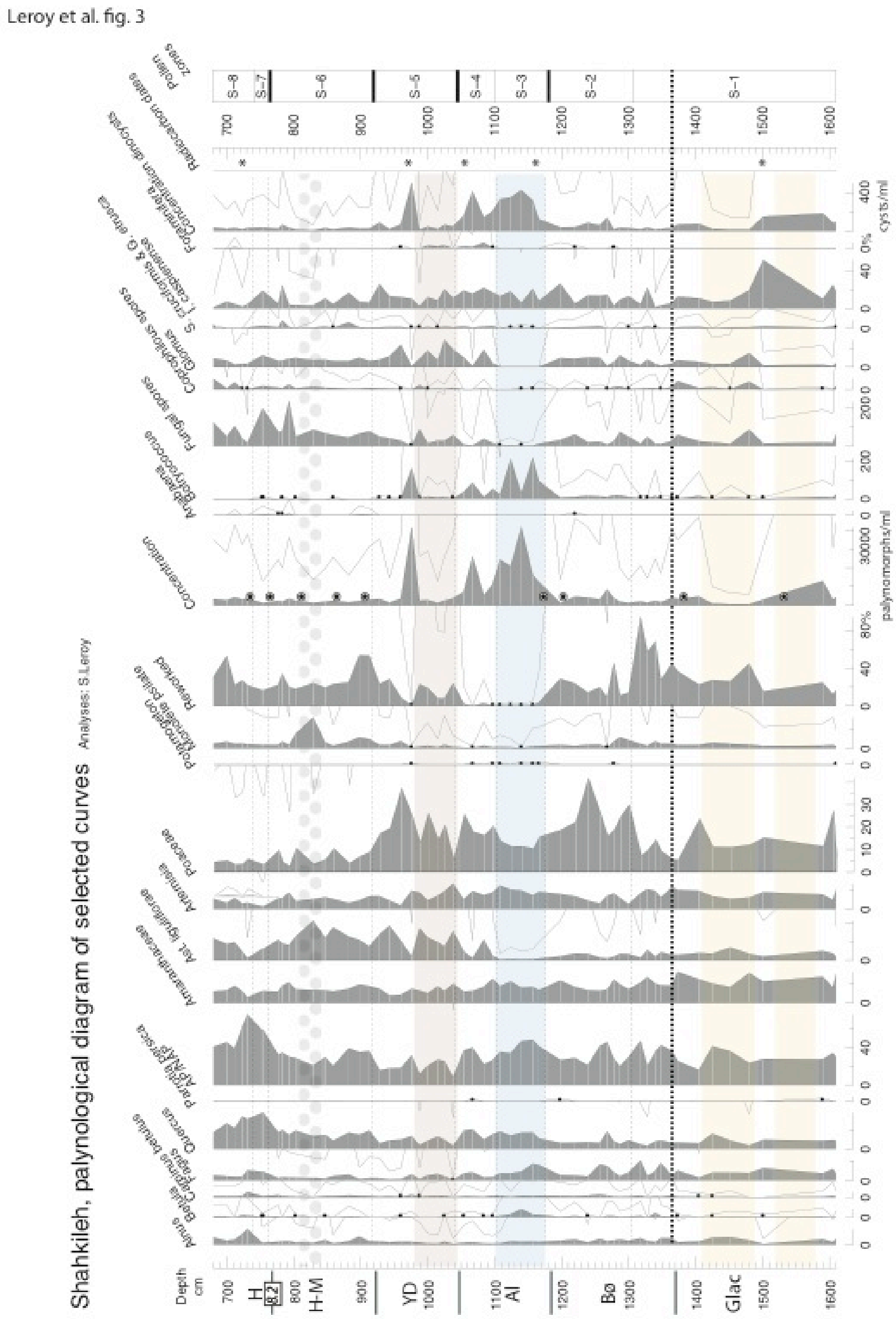


__Fig. 3__: Shahkileh palynological diagram with selected curves (full diagram in Fig. SI 3). Black dot with circle: barren palynological samples. Yellow strips: silt and sandy silt; blue strip: freshwater phase, beige strip: shells, strip with grey circles: gravelly mud horizon. 8.2 in a black box marks the 8.2 cal. ka BP climatic shift. H: Holocene, H-M: Mangyshlak in Holocene, YD: Younger Dryas, Al: Allerød, Bø: Bølling, Glac:

Glacial period. The thick dash line and the thick CONISS zone boundaries are used for the diagram interpretation.

Palynological zone S1 from 1610 to 1369 cm

Tree pollen such as *Alnus, Fagus, Quercus* and *Ulmus-Zelkova* are well represented. *A* maximum of Amaranthaceae characterises this zone. *Artemisia*, Poaceae, and Asteraceae Liguliflorae are abundant. In the spores, the monolete psilate are continuously present. Numerous reworked palynomorphs are observed. The pollen concentration is low, mostly less than 5000 pollen grains per ml.

The dinocysts are relatively abundant and are largely dominated by a large peak of *Impagidinium caspienense*, but most of the other taxa known for the CS at that time are present too (*Pyxidinopsis psilata*, *Spiniferites cruciformis* forms A and B, with a type close to *Galeacysta etrusca*, *S. belerius, Caspidinium rugosum* and *C. rugosum rugosum*, one occurrence of *Lingulodinium machaerophorum* and some *Brigantedinium)*. *Pentapharsodinium dalei* is absent though from this sequence.

Palynological zones S1 from 1369 to 1309 cm and S2 (1309-1182 cm)

Ephedra has the lowest values of the diagram. *Fagus* reaches several times maximal values (up to 21%), while the representation of *Alnus*, *Quercus* and *Ulmus-Zelkova* remains as in the previous zone. *Carpinus* and *Betula* have become quasi continuously present. *Buxus* has three occurrences and *Lonicera* has two single but high peaks. AP reach often as high as 40%. Amaranthaceae decrease, while Poaceae and Cyperaceae increase to maximal values. The end of zone S1 has several samples with very high values of reworked elements (up to 94%).

Typha-Sparganium and *Gloeotrichia* are frequent, especially in zone S2.

Palynological zones S3 (1182-1102.5 cm) and S4 (1102.5–1046 cm)

Alnus percentages decrease progressively throughout zones S3 and S4. *Betula* marks a clear bell-shape maximum in zone S3. After a maximum at the beginning of zone S4, *Fagus* decreases. *Quercus* has significantly high values. *Fraxinus excelsior*-t is frequent. Overall, AP % are often high. Amaranthaceae carry on declining. Liguliflorae percentages, after reaching a minimum, start increasing in zone S4, this most likely explains why the CONISS analysis indicates the strongest change in this sequence in between zones 3 and 4 at 1102.5 cm. Tubuliflorae also increase in zone S4. *Artemisia* percentages are maximal, although always below 25%. Poaceae values have dropped significantly. Fungal spores, *Glomus* and most other fungal spores have low values especially in zone S3. Reworking reaches the lowest percentages of the whole diagram. Pollen concentration is very high, often above 25,000 pollen grains per ml.

In the aquatics, *Potamogeton* pollen marks some regular occurrences in these two zones. The fern spores are infrequent, as well as most other aquatic plants. *Botryococcus* reach extremely high values: up to 190 % of the pollen sum. The dinocysts % are low, and not diverse, especially in zone S3, although their concentration is extremely high, often above 40,000 cysts per ml. Foraminifera linings form for the first time a continuous curve in zone S4.

Palynological zone S5 (1046-920.5 cm)

Most tree pollen grains are low, leading to the lowest AP% of the diagram. Liguliflorae are high, frequently above 25%. After an initial peak at 27%, *Artemisia* declines throughout this zone. Poaceae are high, as in zone S2. Reworked elements increase slowly through the zone. Concentration has fallen back, except in one sample. *Glomus* reaches a maximum several times.

In the aquatics, *Myriophyllum* has an irregular presence. The fern spores and the two taxa of *Typha* are back as in zone S2. *Botryococcus* are low again, except in one sample. *Spirogyra* and *Zygnema* occur in low values at the beginning of the zone. Dinocysts are back as in zone S2. The concentrations are low except in one sample. Foraminifera are frequent in the first part of this zone only.

Palynological zone S6 (920.5 – 766 cm)

CONISS indicates the second most important change at the transition between zones S5 and S6, i.e. at 920.5 cm. Most tree percentages rise gently again, especially *Quercus*. The Liguliflorae are still very high. Poaceae are low from now on, mostly below 10%. In a couple of samples, monolete psilate spores reach values as high as 32 %. Concentration is low, and four barren samples have been encountered. Reworking is high, especially at the beginning of the zone. Fungal spores increase and reach the extremely high percentages of 200 %.

Anabaena starts occurring more frequently. *Botryococcus* are extremely reduced. *I. caspienense* are low, while *Spiniferites cruciformis* reach often 5 %. *Caspidinium rugosum rugosum* is more abundant. The cyst concentration is quite low now and remains so for the rest of the diagram.

Palynological zones S7 (766-742 cm) and S8 (742 – 680 cm)

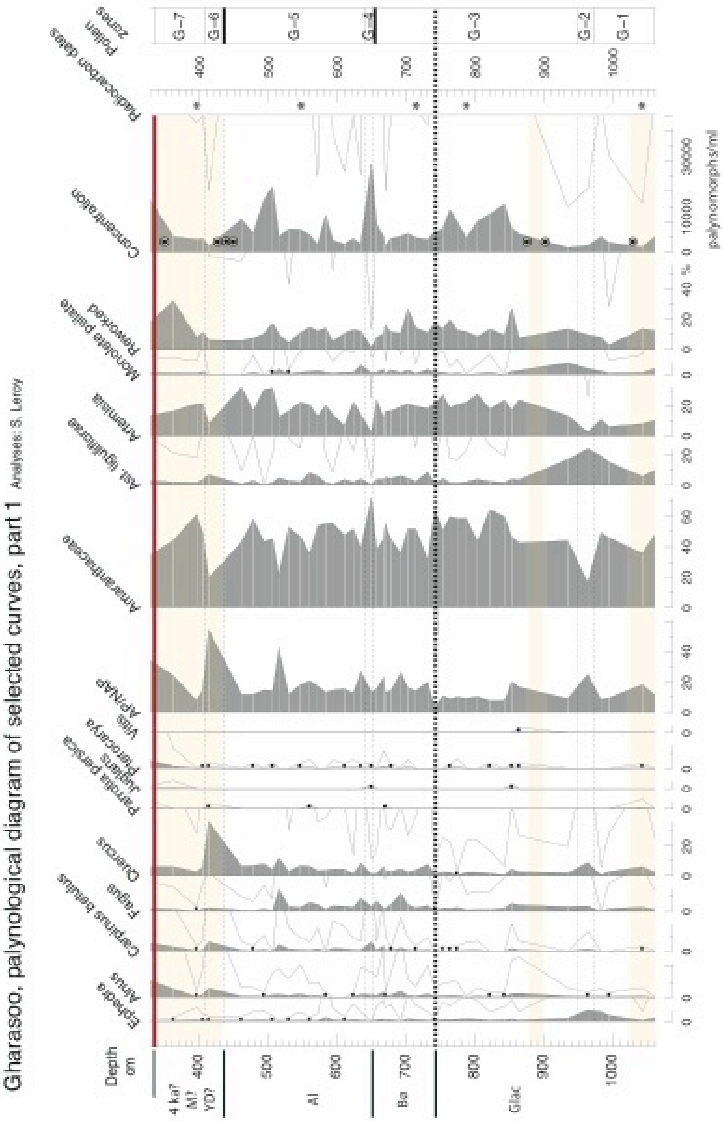
Most tree pollen values increase, specifically *Quercus, Fagus, Alnus, Pterocarya*. AP reach more than 70%. Amaranthaceae, Asteraceae Liguliflorae, *Artemisia* and Poaceae have a weak representation. A peak of reworking occurs towards the top of zone S8. Concentration is low especially in zone S7 that also contains one barren sample. Fungal spores are extremely high in zone S7, as at the end of zone S6. *Sordaria* reach a maximum at the end of zone S8.

Anabaena is still present. Between zones S7 and S8, a clear decrease of the dinocysts occurs.

5.3 Palynology of the Gharasoo sequence

The palynological sequence (52 good samples interspersed by nine barren samples) extends from 1060 to 89 cm depth, with 19 barren samples at the bottom and two at the top (Fig. 4 and Fig. SI 4). Only the diagram below the hiatus at 336 cm depth (i.e. palynological zones G1 to G7) is relevant to this paper.

Leroy et al. fig. 4A



Leroy et al. fig. 4B

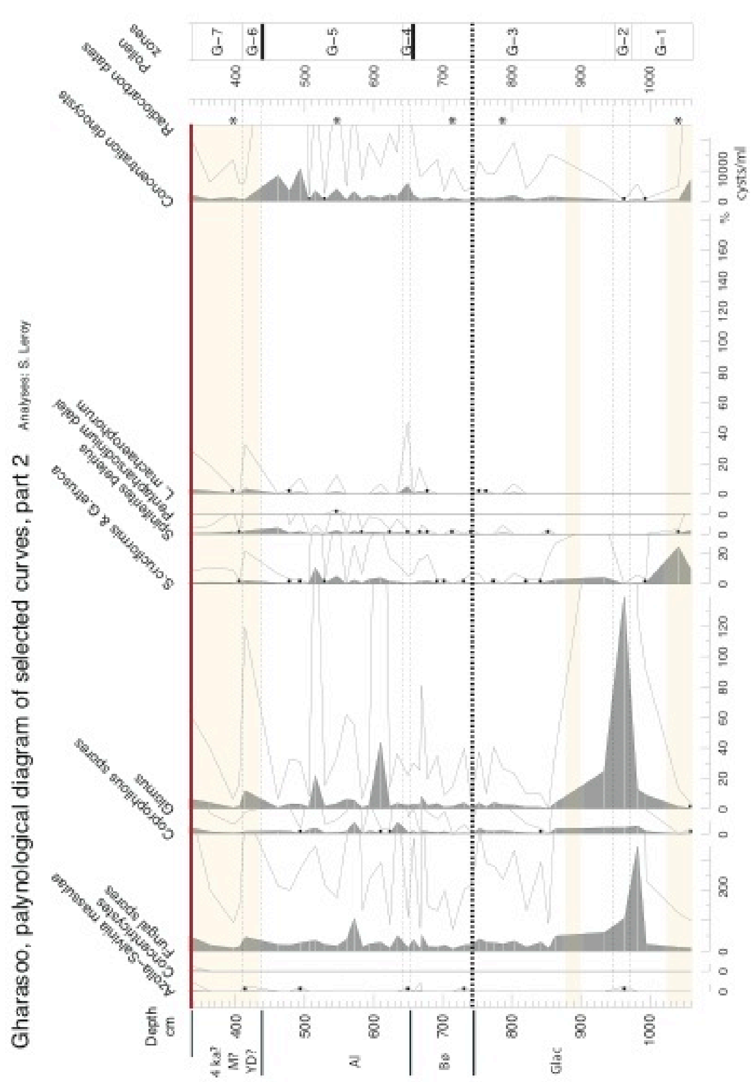


Fig. 4: *Gharasoo palynological diagram with selected curves (full diagram in Fig. SI 4). Black dot with circle: barren palynological samples. Yellow strips: sandy. 3.2 in a black box marks the beginning of L. machaerophorum at 3.2 cal. ka BP (Leroy et al., 2013b). YD: Younger Dryas, Al: Allerød, Bø: Bølling, Glac: Glacial period. The thick dash line and the thick CONISS zone boundaries are used for the diagram interpretation.*

Palynological zones G1 (1060-972.5 cm), G2 (972.5-948.5 cm) and G3 from 948.5 to 736 cm

Ephedra percentages display a maximum. Some tree pollen, such as *Alnus, Carpinus betulus, Fagus, Quercus* and *Ulmus-Zelkova*, are present. Amaranthaceae are dominant, increase across the three zones and reach a maximum (64%) before 736 cm depth. Zone G2 is defined due to a maximum in a bell-shaped curve of Liguliflorae. *Artemisia* is abundant. Concentration increases across the three zones. Fungal spores are abundant and reach a peak at the end of zone G1, whereas *Glomus* peaks in zone G2.

In the aquatics, *Typha-Sparganium* and *Botryococcus* occur regularly. The dinocyst concentration is low. Most taxa are present, except *L. machaerophorum* and *P. dalei,* which are quasi absent.

Palynological zone G3 from 736 to 653 cm

Carpinus betulus becomes continuous. *Fagus, Quercus* and *Ulmus-Zelkova* increase slightly. *Buxus* occurs twice. Amaranthaceae decrease sharply while *Artemisia* decreases slightly across this part of zone G3.

Palynological zones G4 (653-641.5 cm) and G5 (641.5-437 cm)

Ephedra presence becomes discontinuous. *Fagus* is well represented until the middle of zone G5, when its drops and leaves the space to *Quercus* and *Fraxinus excelsior*. *Artemisia* re-increases to maximal values in the second part of zone G5. A single high peak of Amaranthaceae justifies the identification of zone G4.

In the aquatics, *Typha* tetrads after a last occurrence disappear from the record. *P. psilata* is irregularly present and has its last occurrences in this zone. At the end of the zone, *S. belerius* has higher percentages than before. Dinocyst concentration increases in the second half of zone G5, driven by *I. caspienense*.

Palynological zones G6 (437-409 cm) and G7 (409-336 cm)

Only four samples make this double and motley zone, with three barren samples at its beginning and a barren one at its end. Zone G7 ends with the strongest change in the dispersion dendrogram.

The last occurrences of *Elaeagnus* and *Hippophae* are found here. After a single high peak of *Quercus*, its values fall back. *Betula* has the last occurrences of the diagram. Amaranthaceae are high at the beginning of zone G7, but falling afterwards. Reworked values are high at the end of zone G7.

In the aquatics, it is noteworthy to underline the continuous presence of *S. belerius*, although declining. *L. machaerophorum* has irregular and weak presence. The dinocyst concentration is low again.

For chronological purpose, it is additionally essential to indicate that, at 260 cm, *P. dalei* and *L. machaerophorum* are increasing to reach progressively high values, e.g. 184% at 191 cm for *L. machaerophorum*.

5.4 Archaeobotanical and faunal results at Komishani Tappeh

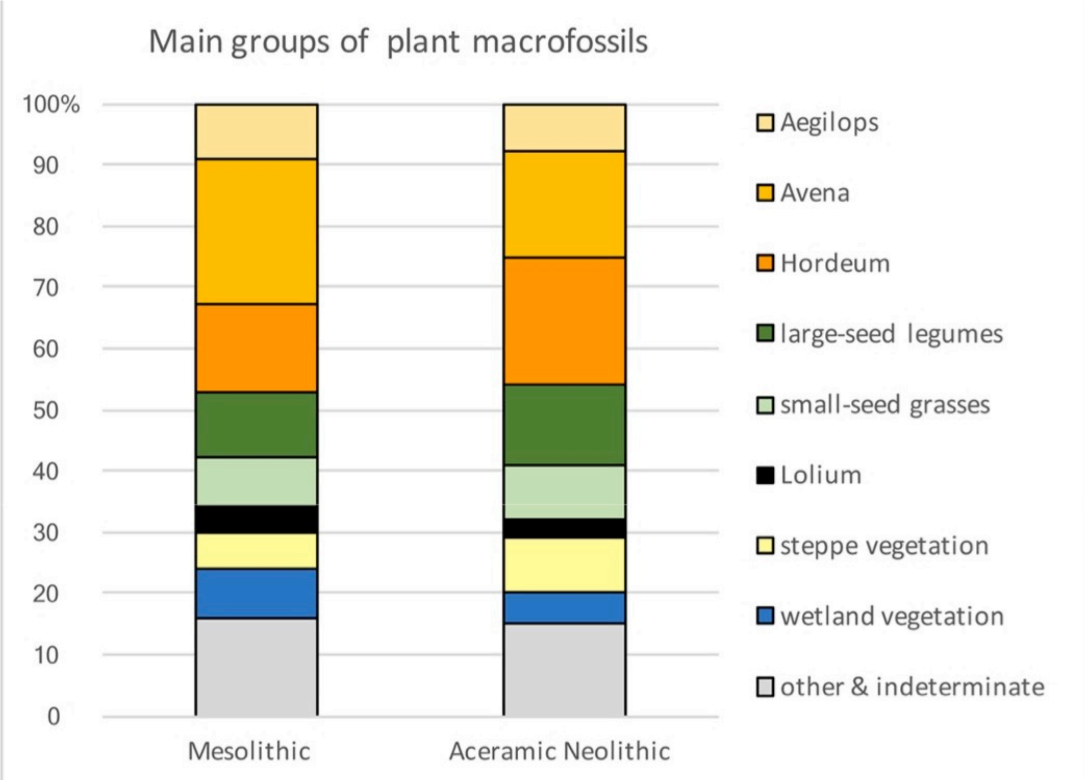


Fig. 5*: Komishani Tappeh: Overview chart of the archaeobotanical evidence. Percentage proportions of the main groups plant macrofossil finds. Fig. 5 (left): Mesolithic: 214 l of sediment, 25 samples, 2415 identifiable plant remains. Fig. 5 (right): Neolithic: 125 l of sediment, 13 samples, 2921 identifiable plant remains*

The study focussed on samples from the lower sequences of the trenches in order to give an overview on archaeobotanical assemblages belonging to the Caspian Mesolithic and aceramic Neolithic. Archaeobotanical analyses of 41 sediment samples (Trench 1, contexts 10 to 23 (9 samples), Trench 2, contexts 4 to 25 (30 samples) and Trench 4, contexts 11 and 13 (2 samples)) yielded 5489 identifiable specimens (Fig. 5). No clear difference between the macrobotanical composition of the two different chronological periods was observed in the studied materials. In some instances, the preservation of plant macroremains did not allow for identification beyond the family level. The botanical assemblage is dominated by large to medium-size seeds from grasses such as *Avena* (wild oats) and *Hordeum* (wild barley), and large-seed legumes and to lesser extend *Aegilops* (goat grass) (Fig. 5 and SI 6).

The underground energy storage organs of an unidentified rhizome or tuber and the seeds of the wetland rush *Bolboschoenus* are present (Fig. SI 6). Twenty seeds of *Hyoscyamus*, a toxic and psychoactive plant commonly known as henbane, were recovered from aceramic Neolithic context 13 in Trench 1 (Fig. SI 6).

Bone samples recovered from Mesolithic (contexts 13-14) and aceramic Neolithic (contexts 8-13) in Trench 4 represent largely consistent and comparable preservation (Fig. SI 2). Bones surfaces are characterized by good states of preservation, ‘ginger’ colour and ‘spikey’ pre-depositional fractures (fragments retaining sharply angular margins to ancient breaks; O’Connor, 1991, 234-235), with relatively low levels of carnivore gnawing and weathering, suggesting relatively quick burial of material which has not suffered significant re-working. Bone samples from later disturbed layers (contexts 2-5) exhibit variable states of preservation. This material is frequently covered in heavy surface concretions and bones are friable and more poorly preserved than the earlier layers. These samples are characterised by quantities of human bones with extensive surface concretions (Table SI 1). A smaller percentage of materials from these disturbed contexts appears well-preserved and resemble those from lower levels. However, less taxonomic diversity occurs in contexts 2, 3, 4 and 5 than in aceramic Neolithic and Caspian Mesolithic levels, which may represent the narrower diet breadth of later farming communities.

Faunal materials from both aceramic Neolithic and Caspian Mesolithic contexts in Trench 4 are characterized by a taxonomic diversity reflecting the broad spectrum of diets known from other Mesolithic and aceramic sites in the Near East (Table SI 1). The mammalian faunal assemblage from these levels is dominated by sheep and goat remains. However, our small sample size currently prevents us from creating herd mortality profiles and drawing meaningful conclusions as to the wild or domesticated status of either species. Waterbirds dominate avian taxa recovered from Mesolithic context 14 and aceramic Neolithic horizons 8 through 13, which provides evidence for the persistence of foraging beyond the emergence of small flint blades and pressure-flaked, single-platform cores in the Caspian basin circa 8600 cal. BC.

Analyses of stable carbon and nitrogen isotope values of 20 animal bones indicated that collagen was sufficiently well preserved in twelve specimens to compare the ratios of $\delta^{13}C$ and $\delta^{15}N$ through the sequence (Text SI 1, table SI2 and fig. SI 7). Ratios of these isotopes are a proxy for animal diet, which can provide useful insights into animal management practices and environmental conditions prevalent during different periods (Lee-Thorp, 2008). Data from these analyses demonstrate that ruminant species consumed predominantly C_3 plants in the Mesolithic and aceramic Neolithic periods (Text SI 1, table SI2 and fig. SI 7). C_4 plants account for less than 0.5% of native species within the modern-day phytogeographic region where Komishani Tappeh is situated (Bocherens et al., 2000:106).

5.5 Radiocarbon dates of the archaeological sites

Forty-seven dates spanning from c.14,800 to c. 5600 cal. BP were used. Only five of them had no faunal or environmental data attached to them. Although the large statistical variability of early radiocarbon dating techniques restricts the ability to use them, eighteen samples provided evidence of seal bones or an indication of transgression (Tables 1 and 2). The latter dates appeared to be arranged in two age groups: one group in the Late Pleistocene and one group around 11,400 to 7300 cal. BP, but more likely 9580 - 8100 cal. BP (Fig. 6).

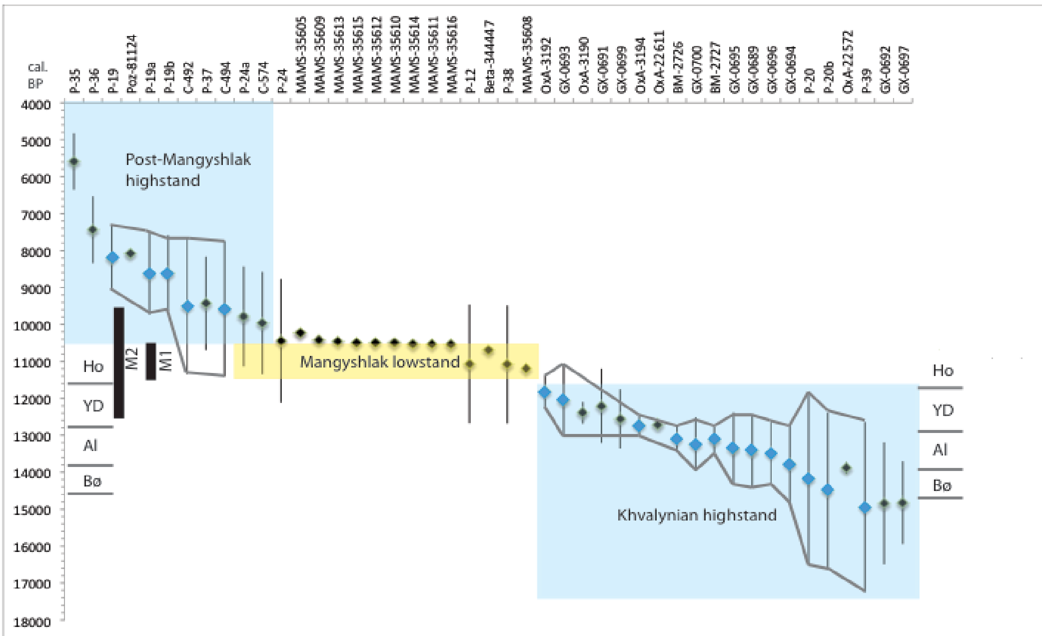


Fig. 6: *Radiocarbon ages in cal. BP of archaeological deposits with evidence of human predation on seals or of highstand in blue and of herbivorous mammals in black. Ho: Holocene, YD: Younger Dryas, Al: Allerød, Bø: Bølling, M1: Mangyshlak lowstand in deep-sea basin (Leroy et al., 2014), M2 in shallow north basin (Bezrodnykh and Sorokhin, 2016). Vertical black boxes: extent of the Mangyshlak lowstand.*

6 Interpretation

6.1 The sequence of Shahkileh

The base of the Shahkileh sequence starts with a sand unit (SU1) that is barren of pollen until 1610 cm depth, and of an age close to the Last Glacial Maximum (Fig. 2A). The Gorgan Bay is very small or has perhaps even disappeared. Pollen zone S1 largely overlaps with the upper part of this sandy unit. The spectra are interpreted as representing a very open landscape with some trees in sheltered areas, such as the slopes of the mountain valleys. This period is suggested to belong to a glacial phase.

The end of zone S1 and zone S2 see the development of vegetation cover. This is interpreted as the start of an interstadial, Bølling-type. Some sand and sandy silt are found in unit SU3. Further vegetation development occurs in zones S3 and S4, which would correspond to a second interstadial phase, Allerød-style. The sediment is fine-grained.

From 1182 to c. 1102.5 cm (zone S3 going into S4), a phase with strong signs of fresh water (*Potamogeton*, high *Botryococcus*, low diversity of dinocysts that are dominated by *I. caspienense*) and lack of erosion (low fern spores, low reworking, well preserved and abundant palynomorphs, low fungal spores) is visible. The landscape corresponds to a forest steppe along the coast. This is most likely still in the Allerød interstadial. The Gorgan Bay is probably very large due to a high stand. It is even possible that the Miankaleh Spit does not exist.

Then the climate deteriorates and the vegetation cover opens (zone S5). The first part of this phase is rich in shells (unit SU5), but the second part is back to a fine-grained sediment. Zone S5 is attributed to the Younger Dryas, with a first brief shallow part (Zygnemataceae and shell-rich layer) and a deeper second part.

With zone S6, the forest redevelops. This is the beginning of the Holocene. The start of the *Anabaena* curve, at base of zone S6, has been elsewhere interpreted as the sign of the beginning of the Holocene (Leroy et al., 2013c, 2014). Zone S6 contains a gravely mud unit (SU7) corresponding to a high-energy environment. It is well–marked by a maximum of psilate fern spores. The number of barren samples also contributes to suggest periods of temporary emersion. Thus overall, zone S6 might fit with the Mangyshlak lowstand, with the gravelly mud corresponding to the lowest stand.

Zones S7 and S8 show a rapid development of diverse coastal and altitudinal forests. The absence of *L. machaerophorum* in zones S7 and 8 suggest that they could still be older than 3200 years ago (Leroy et al., 2013b). It is proposed that the limit between zones S6 and S7 represents the regional increase in humidity subsequent to the 8.2 ka event (Messager et al., 2013; Joannin et al., 2014). The Gorgan Bay is again probably very large.

Then the rest of the sequence is barren of pollen. Towards the top starting around 325 cm, the sediment is oxidised, and from 139 cm it is shelly (unit SU12pp). The lagoon in Shahkileh has filled in. The top metres of the Shahkileh core with the gravelly mud horizons and the shell layers may also have been subjected to significant human impact due to the proximity of a Sasanian wall, i.e. the Tammisheh Wall, and a Safavid harbour, i.e. the Ashraf harbour (Nokandeh et al., 2006; Naderi et al., 2013b).

6.2 The sequence of Gharasoo

Although the interpretation of Gharasoo sequence is less clear than that of Shahkileh, the following may be proposed. The base of the sequence starts with barren units: two fine-grained units (units GU1 and 3) and two sandy/silty ones (units GU2 and 4) of a possible Last Glacial Maximum age (Fig. 2B). The coarse sediment suggests a low water level and an input by the Gharasoo River. The open vegetation at the base of the sequence (zones G1, 2 and 3 until 736 cm) belongs to a glacial period. It contains several sandy/silty layers (units GU4 and GU6pp). Then the warming of the interstadial, Bølling-like, is felt with tree cover increase. Pollen zone G4 is only one sample long, is a brief erosive event, and could potentially be related to one of the brief colder phases of the Bølling-Allerød interstadial. The Allerød is marked by the development of a range of deciduous trees, especially *Fagus* and *Quercus*. Zones G6 and G7 are highly disturbed owing to the occurrence of sand (unit GU8). It could correspond to the Younger Dryas (in the offshore cores GS05 and GS18, *S. belerius* occurs no later than the Late Pleistocene), although the retroactive effect of the successive Mangyshlak and the 4 ka lowstands (for the latter see discussion) could have been superimposed and caused further disturbance to this unit.

Then an important hiatus occurs at 336 cm. Although the late Holocene part of the sequence will be presented elsewhere, it is useful to note that the start of both occurrences of *P. dalei* and *L. machaerophorum* at 260 cm. The latter has been dated in the TM sequence at 3200 years ago (Leroy et al., 2013a,b).

6.3 Archaeobotanical and faunal assemblages from Komishani Tappeh

Preliminary analysis of the well-preserved botanical and faunal assemblages from Komishani Tappeh provides a window into human exploitation of plants and animals from diverse ecological niches at the intersection of the southern coastal plain of the CS and the foothills of the Alborz Mountains during the early Holocene.

6.3.1 Archaeobotanical assemblages

Most of the large seeds (*Avena*, *Hordeum, Aegilops, Stipa* and legume seeds) likely entered archaeological horizons at the site through intensive collection and processing for human consumption (Weide et al., 2018) and correspond well to the pattern of pre-Neolithic plant exploitation in the region (Arranz-Otaegui et al., 2016). This composition with dominance of large seeds and their percentage value (over 50% for both periods) is very similar with what is observed in other Iranian pre-pottery Neolithic sites like East Chia Sabz (53%) and at Chogha Golan (55%) (Riehl et al., 2012).

Elements of the steppe vegetation like *Adonis*, *Stipa* and *Nesslia* occur regularly in the archaeobotanical assemblages and indicate that this habitat was common in the surrounding of the site. *Adonis* and *Nesslia* are known as a weed species incorporated in cultivated field systems in later periods (Whitlam et al., 2018). *Stipa* is usually avoided by animals because its awns and whole florets are dangerous when swallowed by causing damage to the intestines. Therefore Hillmann (2000) proposed that *Stipa* was gathered and processed by people during the Epipalaeolithic and early Neolithic in the Near East for consumption. The abundant *Stipa* finds at early Neolithic Sheikh-e Abad, western Iran (Whitlam et al. 2018: 826-27), can also be interpreted as evidence for human use of this large-seed wild species as a staple food.

Phalaris species have been observed to be seasonal forage for herbivorous mammalian species (Goodin and Northington, 2013). Thus the abundant botanical remains of *Phalaris* and other small-seed species, less numerous in archaeobotanical finds (like *Astragalus* spp., *Chenopodium* spp., *Malva* spp., *Medicago/Trifolium* and *Rumex* spp.), are indicators for the use of dung as fuel at archaeological sites (Van Zeist et al., 1984; Charles, 1996; Whitlam et al., 2018) and thus indirectly suggest increasing intensity of animal management at Komishani Tappeh.

The underground storage organs of *Bolboschoenus* have recently been identified as the source of flour in bread from a 14,000-year-old Natufian hunter-gatherer encampment in northern Jordan (Arranz-Otaegui et al., 2018). Its seeds occur frequently in the samples, most probably because they were processed for food consumption through roasting (Hillmann, 2000) and thus preserved in the cultural layers in charred state as observed in Chogha Golan (Weide et al., 2017). This plant could potentially have been used as a food resource and for matting and dwelling construction at Komishani Tappeh. The finds of *Hyoscyamus* raise questions concerning its potential use for medicinal, spiritual or ritual purposes. The plant usually comes from areas close to humid disturbed habitats, rich in nutrients. So together with *Bolboschoenus,* they represent the use of wetland areas that probably were plentiful in the coastal plains near the site.

6.3.2 Faunal assemblages

Although the recovered faunal sample size is small, several observations can be drawn from the assemblage. A clear similarity in the taphonomic preservation and composition of the remains is observed between the Mesolithic and the Early Neolithic, indicating a degree of continuity.

The diverse environments in the region are represented by the different taxa in the assemblage. For example, the water birds would have access to the coastal water bodies. In terms of the caprines, although wild goats tend to inhabit higher altitudes than sheep, both species may be found at any altitude and their ranges reflect more their habitat preferences. Wild bezoar goats are adapted to rocky substrates and steep slopes, habitats where their morphology enables them the agility to escape predators (Korshunov, 1994; Shams et al., 2010; Weinberg, 2001). Extant populations of Asiatic mouflon (*Ovis orientalis*) inhabit moderately to very arid habitats and particularly grasslands, including mountains, foothills and rolling steppes (Bashari and Hemami, 2013; Valdez, 2008). These habitat preferences mean that minimal competition for food resources exists between wild sheep and goats (Korshunov, 1994). It would be expected for these animals to follow seasonal migrations to make use of available resources at different altitudes throughout the year (Korshunov, 1994; Shams et al., 2010). Hunted animals would therefore represent habitats accessible from Komishani Tappeh and also perhaps indicate seasons of hunting.

7 Discussion

7.1 Varying radiocarbon reservoir effect in the two core sequences

The two sites are in a lagoon, at times directly influenced by the CS, at other times under a more terrestrial influence. Hence it is difficult to decide what calibration curve to choose (INTCAL13 or MAR13). Moreover, it is already known by investigations north of the Miankaleh Spit along a surface transect that the reservoir effect is higher than the 400 yr used for the MAR13 calibration curve and may vary between 670 and 750 yr (Leroy et al., 2018).

When we examined the chronological sequence of the two pollen diagrams in the context of other Caspian sequences, we came to doubt the radiocarbon ages obtained from the Shahkileh and Gharasoo cores. In the Shahkileh sequence, the pollen diagram suggests three rather precise dates (Fig. 2A): the beginning and the end of the Younger Dryas and the 8.2 ka shift (Weninger et al., 2006). Only the end of the Younger Dryas is consistent with the radiocarbon chronology, while the beginning of the Younger Dryas suggested by its radiocarbon age is much too old, i.e. by ~2500-3100 yr, and the 8.2 ka climatic shift is much too late, i.e. by ~2100-2500 yr. The palynology of the Gharasoo sequence (Fig. 2B) suggests that the radiocarbon date for the beginning of the Younger Dryas is similarly too old by ~2500-3100 yr; while the start of the *L. machaerophorum* and *P. dalei* curves at 3.2 ka is slightly too young.

We propose that much like the Black Sea (Soulet et al., 2011), the radiocarbon reservoir effect varies with time in this CS lagoon. Changes in reservoir effect in the Black Sea have been linked to basin hydrology. When the basin is closed, inorganic carbon is increasingly brought by rivers and the reservoir effect increases. Another varying contribution over time is the input of inorganic carbon by rivers according to the weathering intensity in the river catchment (Soulet et al., 2011). These two factors likely played a significant role on the S-E coast of the CS where: 1) the lagoon, at times open – at times confined, received varying amounts of river water; and 2) carbonates from the Kopet Dagh were deposited during the glacial periods when winds were strong and loess formed, as attested for example in the nearby Neka and Toshan regions (Frechen et al., 2009; Vlaminck et al., 2018) (Fig. 1B).

7.2 Water levels, archaeological dates and bones

Both cored sequences show low water levels in the glacial period (most likely the Last Glacial Maximum), followed by high levels in the interstadial. Both records have an important hiatus or period of emersion starting in the mid-Holocene. In Shahkileh, the top c. 7 m of sediment are barren of palynomorphs; while, in Gharasoo, sedimentation and pollen preservation start again after ~>7-8 millennia (not presented here). Shahkileh has slightly more terrestrial and fresher waters than Gharasoo. The latter sequence has occasional occurrences of *Ruppia,* an aquatic plant of brackish waters and less *Potamogeton, Myriophyllum* and *Botryococcus*. The concentration in dinocysts is higher in Gharasoo. Overall this is confirming that the mouth of the lagoon is closer to Gharasoo, as today, and that Shahkileh is usually in a sheltered position behind a spit and readily influenced by freshwater.

The interruption between the two groups of archaeological dates with seal bones or indicators of highstand fits well the age of the Mangyshlak lowstand (Leroy et al., 2013c, 2014; Bezrodnykh and Sorokin, 2016) (Fig. 6; Tables 1 and 2). The large coastal plain in front of the caves extended hundreds km northward (Fig. 1A), as the bathymetry north of the Miankaleh Spit is very shallow (mostly less than 20 m) (Leroy et al., 2018), Gorgan Bay itself would have been much reduced or non-existent. The oldest group of dates with seals and highstand indicators in the Late Pleistocene corresponds to the Khvalynian highstand, whereas the youngest group of dates suggest the post-Mangyshlak highstand (Leroy et al., 2019; in press).

7.3 The Last Glacial Maximum and the 4 ka questions

For the Last Glacial Maximum, the literature shows contradictory information about the water levels in the CS, highstand or lowstand (Leroy et al., in press). Using the ages proposed by the pollen diagram and applying a correction of 2500-3100 years, the bottom of each core reaches the Last Glacial Maximum. In both localities, the sediment is sandy and barren of palynomorphs, suggesting a lowstand. This is in agreement with the Last Glacial Maximum when CS level reached 50 to 113 m bsl, which is equivalent to the Eltonian, Atelian or Enotayevian lowstand, various names according to different authors (Varushchenko et al., 1987; Chepalyga, 2007; Svitoch, 2009;

Yanina 2014; Yanina et al., 2018). Moreover the results of climate modelling by Arpe et al. (2011) are also in favour of a lowstand for the Last Glacial Maximum.

In the Shahkileh sequence, the sediment is barren of palynomorphs after c. 4 cal. ka BP, probably by oxidation caused by temporary emersion. In the Gharasoo sequence, an especially long hiatus occurs between <12.9 (end of Allerød) and >4.0-3.5 cal. ka BP (radiocarbon date at 310 cm). This may result from the retro-active effect of the Younger Dryas, 4 ka event and Mangyshlak lowstand leading to erosion of the underlying sediment (Leroy et al., 2013a). An important change in dinocyst assemblage from low salinity to more brackish has been noted in three deep-sea sequences: in the south basin (cores CP14, GS05), in the middle basin (core GS18) and in the north of middle basin (core Sh7) (Leroy et al., 2007, 2013 c, 2014, and 2019). Along the coast, this 4 ka period is moreover marked by barren levels topped by gypsum, due to emersion in a lagoon of the SE of the south Caspian basin (core TM) (Leroy et al., 2013a). Thus overall six sites show evidence of deep changes in the CS at 4 ka. It has been recently suggested that its origin could be found in hydrographic changes with a sharp reduction of the Amu-Darya inflow to the CS and the end of a humid period over the Karakum Desert (Leroy et al., 2019) due to the decrease of meltwater into rivers flowing from the Hindu-Kush to the Karakum, such as the Murghab River (Fig.1A).

7.4 Vegetation and herbivorous animals

When comparing the two sequences, it appears that Shahkileh has higher AP% than Gharasoo in the Pleistocene. *Elaeagnus*, a small tree of dry lands, is frequent in Gharasoo. Amaranthaceae percentages are commonly higher in Gharasoo in agreement with modern spectra (Leroy et al., 2013a). *Buxus* makes a brief appearance in the Bølling phase of the two sequences. The AP% is higher in the Shahkileh sequence than the Gharasoo one (in a more eastward position), and higher in the Gharasoo sequence than in core TM (further to the North and further away from the mountains) (Leroy et al., 2013a). This thus reflects well humidity gradients along the southern coast from the west to the east and along the east coast from the south to the north, as is the case today.

The Mesolithic charcoal assemblages found in the Ali Tappeh Cave (Shirazi, unpublished data) fit rather well the Younger Dryas pollen spectra of the Shahkileh sequence. Especially as it reveals the abundance of flowering species of the Rosaceae family, which are often undetectable through pollen analysis, but may have provided hunter-gatherers with a source of edible fruits, such as plums, peaches, apricots, or almonds. A comparison of pollen and macroremains is inadequate due to the low taxonomical resolution of pollen analysis. However, it should be noted that Cerealia-t. pollen occurs continuously but irregularly in the Lateglacial of both cored sequences.

A feature of both sequences is the continuous presence and the diversity of the deciduous trees during the pre-Holocene period, i.e. not only *Acer, Alnus, Betula, Carpinus betulus, Fagus, Quercus, Tilia,* but also *Pterocarya* and *Ulmus-Zelkova*. The existence of refugia during the Last Glacial Maximum at the foot of the Alborz Mountains was hypothesised from climatic modelling (Leroy and Arpe, 2007; Arpe et al., 2011). It is likely that, during the Younger Dryas, this niche-rich region was also a refuge, although no climatic models are available at the moment to corroborate this. During the Younger Dryas, only a slight drop of the arboreal cover was observed: AP % drop to 19%, compared to values of 33 % before and 30 % after (Shahkileh sequence). Thus, this forested steppe vegetation is reflective of climatic conditions far from the extremes of glaciation, and which would have been conducive to the survival of a wide range of mammalian species and persistence of human occupation of the region.

The diverse vegetation cover reconstructed from palynology, anthracology and archaeobotany is suitable to sustain the range of herbivorous mammals found in the bone assemblages (Tables 1 and 2). Nowzari et al. (2007) have observed that Goitered gazelle (*Gazella subguttorosa*) prefer *Astragalus* and *Ebenus* for food and shelter, and feed on plant communities dominated by *Bromus danthoniae* and *Stipa barbata* (the latter may be eaten before flowering, not afterwards, see earlier comments) during autumn and *Astragalus spp., Poa bulbosa, Aegilops umbellulata,* and *Bromus danthoniae* in winter*. Artemisia spp*. and *Astragalus spp*. are also found in most habitats of wild sheep (*Ovis orientalis)* in Iran today, where, as Bashari and Hemami (2013) have noted, the higher risk of predation on plains results in preferential feeding on upland pastures. Similarly, Morovati et al. (2014) conclude that the most important factors affecting desirability of habitats for wild goat populations (*Capra aegagrus)* are the ratio of distances to rocky cliffs and slopes, and distance to water and food resources such as *Artemisia sieberi*. The preferred habitats of wild aurochs remain uncertain, as *Bos primigenius* and its descendant species are known to have occupied a broad range of niches, including river valleys and deltas, deciduous forests, deserts, upland steppes and grasslands (Van Vuure, 2005). Red deer (*Cervus elaphus*), once abundant on the forested northern slopes of the Alborz and western slopes of the Zagros in historically known periods, are now confined to a number of remote wooded reserves in the central and eastern Alborz (Encyclopaedia Iranica, 2005).

7.5 Environment – human interactions

7.5.1 The McBurney hypothesis

The continuous presence of spores from coprophilous fungi in the Shahkileh and Gharasoo sequence confirms the presence of grazing herbivorous mammals (Cugny et al., 2010). This continuity is only interrupted in the Shahkileh record by indicators of freshwater aquatic organisms (*Potamogeton* and *Botryococcus*) and still water (fine-grained sediment and the maximum of organic matter in unit SU4, and the absence of erosional indicators) in the first part of the Allerød interstadial. At that point the coastal plain was likely to have been very narrow, which might explain the presence of seal bones in the basal Mesolithic occupation levels at Belt, Hotu and Ali Tappeh Caves (Fig. 6). The close proximity of the Caspian shore likely facilitated easy transport of seal from hunting grounds to the caves where they were consumed in an increasingly sedentary pattern of resource procurement.

If the gravelly mud in unit SU7 of the Shahkileh core indeed corresponds to the greatest extent of the Mangyshlak lowstand, the coastal plain would have been much wider than at present. The absence of seal bones in archaeological horizons corresponding to this period at Belt, Hotu, Ali Tappeh and Komishan Caves suggests that Mesolithic hunters and gatherers had difficulties in accessing this animal (Fig. 6). Consequently, the inhabitants of these rock shelters came to rely on a much broader range of mammalian species, including gazelles, aurochs, sheep, goats and equids, adapted to the open vegetation covering the greatly enlarged coastal plain and nearby foothills of the Alborz Mountains.

This confirms the two parts of McBurney hypothesis.

7.5.2 Early Neolithization

The botanical, faunal and archaeological evidence from Komishani Tappeh strongly suggests that the management of wild plant and animal resources preceded the local emergence of a low-level food-producing society on the southern coastal plain of the CS during the early Holocene. Continuities in the botanical and faunal assemblages of Mesolithic and Neolithic horizons demonstrate that the process of Neolithization occurred over a prolonged period between 9200 and 8200 cal. BC. Coupled with a botanical assemblage dominated by large to medium-size seeds, such as wild oats, wild barley, goat grass and leguminous seeds, the first appearance of ground stone tools in the region comes from the earliest Mesolithic level able to be dated at the site (9200 cal. BC). The aceramic Neolithic levels bearing small flint blades and pressure-flaked, single-platform cores at the site all fall between 8600 and 8200 cal. BC.

This early process of Neolithization in the southern Caspian basin was most likely facilitated by favourable environmental conditions at the time as well as those preceding it. Unlike other localities in southwest Asia where lacustrine and pollen records indicate water levels dropped dramatically and vegetation turned to semi-arid (Wick et al., 2003; Wasylikowa, 2005; Stevens et al., 2012), our evidence shows that the cool and dry conditions often associated with the Younger Dryas (Jones et al., 2019) do not appear to have been as extreme in this region. Thus, increasingly sedentary hunting and gathering groups could have drawn on plant and animal resources from multiple ecological niches at the intersection of the southern coastal plain of the CS and the foothills of the Alborz Mountains, without suffering significant resource stress or reduced population levels that may have been encountered in neighbouring regions (Baird et al., 2013).

Palynological evidence for the development of deciduous forest (mostly oak) found in the Shahkileh sequence in zones S7 and S8 is similar to that in core GS 18 after 8.2 cal. ka BP (in the middle CS basin) and in core GS05 after 8.4 cal. ka BP (in the southern CS basin) (Fig. 1A). These indicators of climate amelioration fit well with the emergence and/or dispersal of agricultural ways of life throughout western central Asia. Wetter climatic conditions (called the Liavliakan phase) have been recorded between ~8.8 and 4.5 cal. ka BP (published as 8 to 4 ^{14}C ka BP) in lands between the foothills of the Kopet Dagh and the western edge of the Karakum Desert (Lioumbimtseva et al., 1998). These climatic conditions likely facilitated the adoption of agriculture at the late Neolithic agricultural village of Jeitun between 6400 and 5600 cal. BC (Masson, 1957; Harris et al., 1993; Harris,

2010) (Fig. 1A). No clear-cut trajectory for the dispersal of agricultural or agropastoral ways of life from the Near East to other regions in Asia has been established (Gangal et al., 2014). However, recovery of Caspian 'soft' ware pottery fragments from otherwise aceramic contexts and basal pottery-bearing horizons at Sang-e Chakhmaq (at c. 130 km east of Behshahr, on the southern flank of the Alborz Mountain and at c. 1400 m elevation, Fig. 1B) (Nakamura, 2014; Tsuneki, 2014) supports the idea that pottery making was adopted on the southeastern flanks of the Alborz Mountains from an independent centre of 'Neolithization' in the Caspian basin in the 7th millennium BC (Gregg and Thornton, 2012). On the north-eastern foothills of the Alborz Mountains, the recovery of unfired and fired clay objects from Mesolithic levels at Belt and Hotu Caves (Coon, 1951,1952; Dupree, 1952), not only attests to a 'Mesolithic interest in clay' as Coon suggested, but also allows for the potential independent invention of pottery in this region during later Neolithic periods (Gregg and Thornton, 2012).

8 Conclusions

These investigations have identified a significant problem with radiocarbon dating of organic materials of marine origin in a southern Caspian lagoon during the Late Pleistocene, due to the large reservoir effect resulting from carbonate inputs from the Kopet Dagh and the foothills of the Alborz Mountains. Nevertheless, the two sequences of Shahkileh and Gharasoo do provide sedimentological and palynological evidence for environmental change during the terminal Pleistocene and early Holocene, a time period when major transformations in human subsistence and social practices, including related innovations in chipped stone, ground stone and ceramic technologies, emerged and dispersed throughout the region.

The Shahkileh and Gharasoo sequences record a period of high CS levels in the Late Pleistocene. In Shahkileh, specifically in the Allerød Interstadial, a phase of abundant freshwater and a decline of the herbivore grazing indicators is found. This evidence of high CS levels, when coupled with the earliest seal-bearing occupations of Ali Tappeh Cave dating between 11,500 and 10,500 cal. BC, supports the first part of McBurney's hypothesis that when CS levels were high and the coastal plain was narrow, Mesolithic hunters were reliant on seal and deer. The sequences provide evidence of three lowstands, the Last Glacial Maximum, the Mangyshlak, and the 4 ka event, before the local infilling of the lagoon. The Mangyshlak lowstand would have greatly enlarged the coastal plain and provided habitats for the broad range of mammalian species found in faunal assemblages of the Mesolithic and/or Neolithic occupations of Belt, Hotu, Ali Tappeh and Komishan Caves and Komishani Tappeh, thus supporting McBurney's second contention that as water levels receded and a wide coastal plain emerged, hunters consumed different range of species, including auroch, onager, boar, gazelle, sheep and goat.

A combination of palynology, anthracology and plant macroremains, rare for the studied region, allowed the reconstruction of vegetation. The presence of animal bones attested of the occurrence of herbivorous animals and their use by prehistoric population in the Mesolithic and Neolithic periods. All proxies indicated the diversity of ecological niches and the continuous presence of wetlands. During the Younger Dryas, a diverse range of deciduous trees persisted in this region indicating climatic conditions favourable for a broad variety of plant and animal food resources, and hence for human survival. This may explain the early process of Neolithization on the southern coastal plain of the Caspian Sea, which had its roots in a relatively benign impact of the Younger Dryas stadial.

Faunal, botanical and archaeological evidence from Komishani Tappeh demonstrate that this process of Neolithization was a very gradual, low-cost adaptation to new ways of life, with neither the wholesale abandonment of hunting and gathering, nor a climatic trigger event for the emergence of a low-level, food-producing society. This evidence shows that Mesolithic hunters and gatherers were targeting sheep and goat populations, collecting wild oats and wild barley and legumes and using ground stone tools as early 9200 cal. BC. Whereas, evidence recovered from Neolithic occupations of this site indicate its inhabitants continued to rely on wild plant and animal resources for at least 400 years following the first appearance of small flint blades and pressure-flaked, single-platform cores circa 8600 cal. BC.

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